SEWAGE WORKS JOURNAL

Vol. VII NOVEMBER, 1935 No. 6

Special Articles

Chemical Treatment of Sewage
A Committee Report—Pearse, Chairman

Sterilization and Filtration of Secondary Sludge—Kaefer

Chlorination and Bacterial Aftergrowths—Rudolfs

The Disposal of Sewage Solids—Mohlman

OFFICIAL PUBLICATION OF THE
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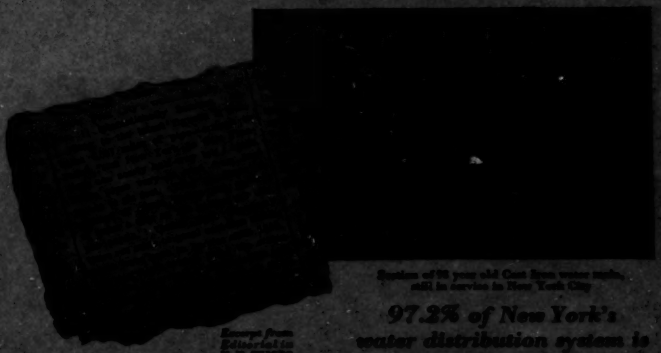
NEW YORK'S...

Underground Empire

(4587 MILES OF WATER MAINS)



Section of 72 year old Cast Iron water main, still in service in New York City

Source from Interstate N.Y. TIMES

97.2% of New York's water distribution system is cast iron pipe

APPROXIMATELY two million lengths of pipe of which 97.2% is cast iron pipe distribute water to the five boroughs of New York City—4587 miles of distribution mains which if laid in a straight line would reach from New York to San Francisco and nearly half way back again—this is New York's "underground empire." These mains distribute 900,000,000 gallons of water per day. Some sources are more than 100 miles distant. Capacity of storage reservoirs is 285,000 million gallons. The average percentage of cast iron pipe in the water distribution systems of the 15 largest cities in the United States is 96.6%.

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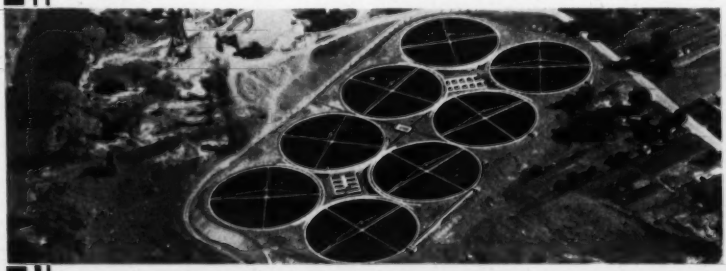

Aerial view of Cedar Rapids trickling filter installation. Eight 167 ft. Dorrco Distributors used.

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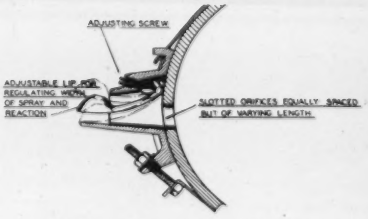
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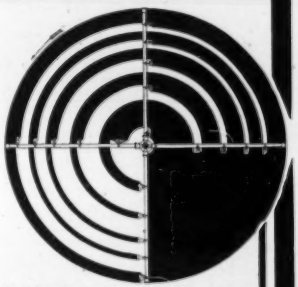

Individually, every spray wets its own particular ring of bed area, as shown in southwest quadrant. Collectively, all of the sprays wet all of the bed area, as shown in southeast quadrant.

Here are the results which speak for themselves:

Trickling Filter	*Gals./ Sq. Yd./ Day*	*Per Cent of Average*	*Per Cent Variation*
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No. 2	626	99.52	−0.48
No. 3	636	101.11	+1.11
No. 4	626	99.52	−0.48
No. 5	634	100.79	+0.79
No. 6	620	98.57	−1.43
No. 7	613	97.46	−2.54
No. 8	647	102.86	+2.86
	Av. 629		

- The greatest variation from the average rate of delivery was + 2.86 per cent and the average variation for all 8 trickling filters 1.2 per cent.
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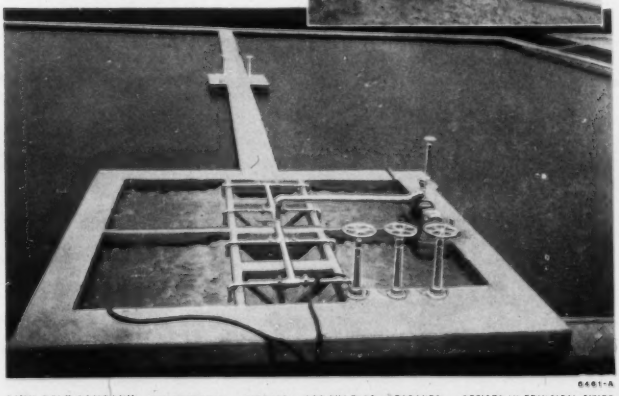

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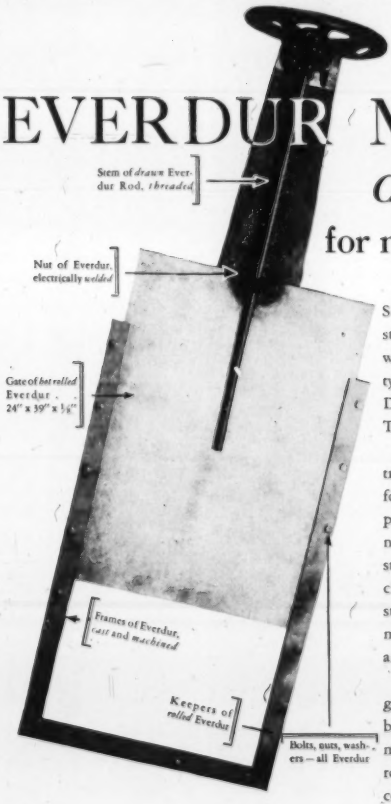
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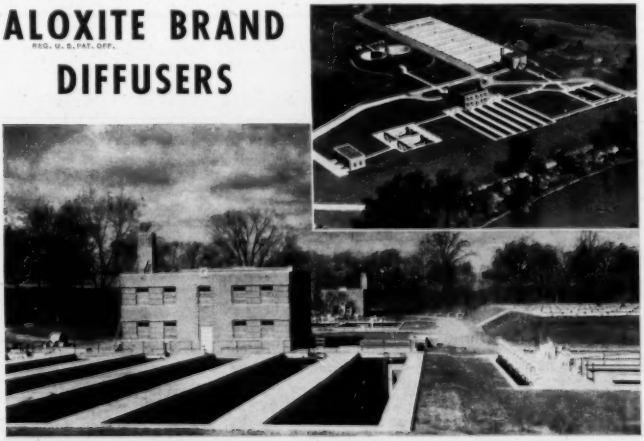

Lancaster, Pa. Sewage Treatment Plants. South Side Plant above. North Side Plant below. Chester, Laboon, Campbell, Davis and Bankson (formerly J. N. Chester Engineers), Consulting Engineers. Aloxite Brand Diffuser Plates used exclusively.

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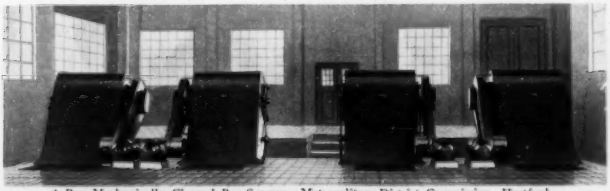
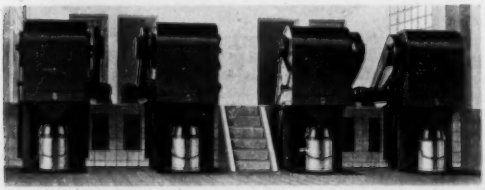


4 Rex Mechanically Cleaned Bar Screens—Metropolitan District Commission, Hartford, Connecticut. Note the neat appearance—the easy method of screenings disposal.



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A new Catalog—No. 259—gives full details on the advantages of Rex Mechanically Cleaned Bar Screens—and their application. You will find it useful in your work—send for your copy.

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Rex Bar Screens, Sludge Collectors and Sludge Pumps are products of a specialized division of the Chain Belt Company that dates back to 1917.

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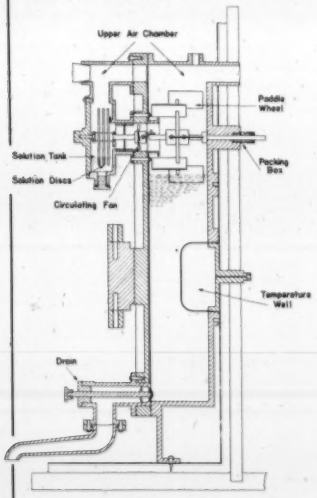

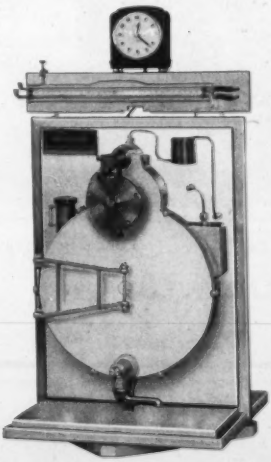

The advantages of this method over the dilution chemical test method are:

1. The sample used for testing is so large that it can be relied upon as being a representative sample.
2. The apparatus determines rates of oxygen demand which are probably more important from a practical standpoint than 5 day total demands.
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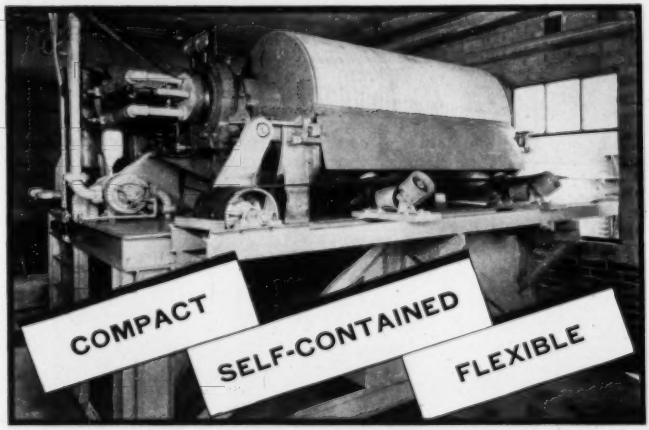

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Sewage Research

VACUUM FILTRATION OF SLUDGE FROM SECONDARY SETTLING TANKS

By C. E. Keefer and Herman Kratz, Jr.

Principal Assistant Engineer and Junior Chemist, Bureau of Sewers, Baltimore, Md.

The feasibility of dewatering primary settling tank sludge on vacuum filters at the Baltimore sewage works has been demonstrated during the past few years by an extended group of experiments.[1, 2] These investigations have been supplemented in order to learn how readily sludge from secondary settling tanks, which treat the effluent from trickling filters, could be dewatered. The work consisted of filtering both raw and semi-digested secondary settling tank sludge separately and when mixed with digested primary settling tank solids. These sludges were filtered both before and after elutriation. Ferric chloride and chlorinated copperas were used as coagulants. The experiments have indicated that it is much more difficult to filter sludge from secondary sedimentation tanks than digested solids from primary settling tanks. Better results were obtained when the material was allowed to digest to a certain extent before filtering. The highest capacities—comparable with those when dewatering digested primary settling tank sludge—were obtained when a mixture of semi-digested sludge from secondary settling tanks and digested primary tank sludge was filtered.

Filtering Undigested Secondary Settling Tank Sludge

All of the sludge was dewatered by means of an Oliver vacuum filter. The material was obtained from the secondary settling tanks, which receive the effluent from 30 acres of trickling filters at the Baltimore sewage works. The sludge was pumped into an overhead storage tank and filtered as required.

Coagulation With Ferric Chloride.—Ferric chloride was used as a coagulant during the first group of tests. The results are shown in Table I and Figure 1. Two runs were made to see to what extent various quantities of this chemical would affect the filter capacity when dewatering unelutriated sludge. During the first run from 3.5 to 12.7 lb. of anhydrous ferric chloride was used per 100 lb. of dry solids in the sludge. The cake output varied from 0.9 to 1.6 lb. of dry solids per square foot of filter area per hour. The material before filtration was

TABLE I.—*Vacuum Filtration of Raw Secondary Tank Sludge Coagulated with $FeCl_3$*

(Tests made March 7–22, 1935)

Test No.	Duration of Test,	Digested Sludge				Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids,	Cake		Effluent			Filter Operation	
		Solid Content,	Volatile Matter,	Amino Ammonia Nitrogen,			Dry Cake per Sq. Ft. of Filter Area per Hr.,	Moisture,	B.O.D. 5-day at 20° C.,	Suspended Solids,		Speed,	Vacuum,
	Min.	%	%	P.p.m.	pH	Lb.	Lb.	%	P.p.m.	P.p.m.	pH	Sec. per Rev.	In.
Secondary Tank Sludge—Not Elutriated													
Run No. 1													
1	15	2.5	74.9	160	6.3	10.2	1.2	85.0	330	78	—	308	18
2	10	2.5	74.9	160	6.3	12.7	0.9	84.8	370	22	2.2	360	18
3	10	2.6	72.5	155	6.3	7.3	1.4	85.2	170	22	3.6	360	18
4	10	2.6	72.5	155	6.3	4.8	1.3	86.1	90	29	4.1	360	18
5	10	2.6	72.4	160	6.3	8.3	1.6	85.1	310	20	3.5	360	18
6	10	2.6	72.4	160	6.3	3.5	1.0	85.9	—	—	4.3	360	18
Run No. 2													
7	10	2.5	73.8	205	6.3	7.7	1.0	87.3	110	46	4.3	319	17
8	10	2.5	73.8	205	6.3	10.2	0.9	86.5	630	113	3.9	315	17
9	12	2.4	74.2	200	6.3	9.0	1.0	86.8	380	38	3.7	368	19
10	10	2.4	74.2	200	6.3	6.9	1.0	87.0	107	45	4.0	368	18
11	10	2.4	74.7	200	6.3	5.2	0.9	87.6	70	47	4.3	368	19
12	10	2.4	74.7	200	6.3	4.2	0.7	88.0	73	53	4.6	368	18

TABLE I—*Continued*

Secondary Tank Sludge—Elutriated With 2 Parts of Water [1]

Run No. 1

13	10	2.6	72.8	90	6.5	5.2	1.3	86.1	165	16	4.1	344	17–18
14	10	2.6	72.8	90	6.5	6.6	1.1	85.0	152	33	3.7	344	17–18
15	10	2.6	72.5	90	6.5	4.1	1.6	85.9	119	27	4.3	300	17–18
16	10	2.6	72.5	90	6.5	2.8	1.1	86.2	88	29	4.5	320	17–18

Run No. 2

17	10	2.4	72.2	95	6.5	5.9	1.1	85.4	119	31	3.9	315	17–18
18	10	2.4	72.2	95	6.5	4.6	1.3	86.4	67	39	4.3	315	18
19	10	2.6	72.7	90	6.5	3.1	1.0	87.0	71	41	4.5	315	18–19
20	10	2.6	72.7	90	6.5	3.7	1.1	87.2	78	39	4.4	315	18–19

Primary Tank Digested Sludge—Not Elutriated

21	6	7.0	52.0	810	7.1	7.3	13.1	76.7	76	131	5.9	56	17–18
22	6	7.0	52.0	810	7.1	5.5	7.7	76.9	46	84	6.2	105	17–18
23	10	7.2	51.6	820	7.2	3.6	4.3	76.4	39	142	6.8	187	17–18
24	6	7.2	51.6	820	7.2	6.2	12.8	77.0	50	103	6.2	49	18

Elutriated With 2 Parts of Water [2]

25	10	7.2	50.4	260	7.1	1.8	6.4	76.5	68	80	6.5	114	17–18
26	10	7.2	50.4	260	7.1	2.5	11.1	76.2	50	69	6.2	70	17–18
27	10	7.6	50.6	225	7.1	3.0	15.2	76.0	38	62	6.0	49	17
28	7	7.6	50.6	225	7.1	3.7	22.1	76.8	42	63	5.9	34	18
29	6	7.4	51.3	240	7.1	4.5	25.5	77.3	62	79	5.7	25	17

[1] Secondary tank sludge was elutriated in 2 steps. Elutriate from 1st step contained 362 p.p.m. B.O.D. (5 days at 20° C.), 352 p.p.m. suspended solids. Elutriate from 2nd step contained 170 p.p.m. B.O.D. (5 days at 20° C.), 220 p.p.m. suspended solids and had a pH value of 6.2.

[2] Primary tank digested sludge was elutriated in 2 stages. Elutriate from 1st stage contained 55 p.p.m. B.O.D. (5 days at 20° C.), 500 p.p.m. suspended solids and had a pH value of 7.5. Elutriate from 2nd stage contained 103 p.p.m. B.O.D. (5 days at 20° C.), 364 p.p.m. suspended solids and had a pH value of 7.3.

TABLE I—*Continued*

Test No.	Duration of Test,	Digested Sludge				Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids,	Cake		Effluent			Filter Operation	
		Solid Content,	Volatile Matter,	Amino Ammonia Nitrogen,			Dry Cake per Sq. Ft. of Filter Area per Hr.,	Moisture,	B.O.D. 5-day at 20° C.,	Suspended Solids,		Speed,	Vacuum,
	Min.	%	%	P.p.m.	pH	Lb.	Lb.	%	P.p.m.	P.p.m.	pH	Sec. per Rev.	In.
Secondary Tank Sludge (1 Part) and Primary Tank Digested Sludge (4 Parts)—Not Elutriated													
30	10	4.4	57.8	490	6.9	10.7	5.7	80.8	360	96	4.9	83	18
31	10	4.4	57.8	490	6.9	7.2	4.4	81.0	125	73	4.9	144	18–19
32	10	4.2	59.1	490	6.9	3.8	1.8	81.8	152	44	6.0	300	18
33	10	4.2	59.1	490	6.9	9.5	5.2	82.0	210	53	4.9	96	18–19
34	10	4.3	58.0	490	6.9	13.0	4.0	82.0	580	60	—	130	18–19
Elutriated With 2 Parts of Water[a]*—Run No. 1*													
35	6	4.2	59.1	180	6.6	6.0	8.4	79.9	129	54	4.9	55	18
36	5	4.2	59.1	180	6.6	7.5	10.5	81.1	172	82	4.0	34	18–19
37	7	3.9	59.9	155	6.6	4.9	6.6	80.4	118	44	4.5	75	18–19
38	10	3.9	59.9	155	6.6	3.2	4.6	80.1	137	35	5.1	105	18–19
Elutriated With 2 Parts of Water—Run No. 2													
39	10	3.9	59.8	170	6.7	4.0	3.7	79.5	66	21	5.3	163	18
40	8	3.9	59.8	170	6.7	5.7	5.6	80.0	107	9	4.9	93	18
41	8	3.9	59.4	165	6.6	7.3	6.3	80.4	94	8	4.2	68	18–19
42	9	3.9	59.4	165	6.6	9.0	5.2	80.0	181	24	3.1	68	18–19

[a] Mixture was elutriated in 2 stages. Elutriate from 1st stage contained 490 p.p.m. B.O.D. (5 days at 20° C.), 460 p.p.m. suspended solids and had a pH value of 6.9. Elutriate from 2nd stage contained 310 p.p.m. B.O.D. (5 days at 20° C.), 316 p.p.m. suspended solids and had a pH value of 6.9.

quite wet, containing about 2.6 per cent solids. The volatile solids in the sludge averaged 73.3 per cent, and the amino-ammonia nitrogen amounted to 158 p.p.m. The moisture in the cake was high, varying from 84.8 to 86.1 per cent. A second run was made with similar results except that the maximum cake production was 1.0 lb. of dry solids per square foot of filter area per hour.

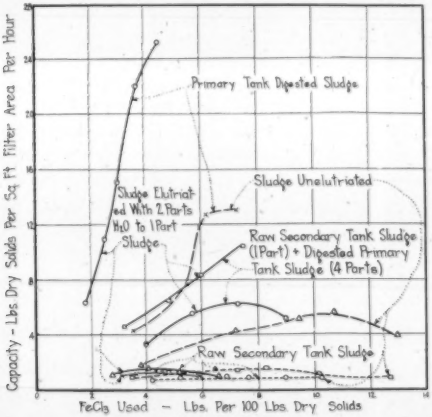
Capacity - Lbs. Dry Solids Per Sq. Ft. Filter Area Per Hour
Primary Tank Digested Sludge
Sludge Unelutriated
Sludge Elutriated With 2 Parts H2O to 1 Part Sludge
Raw Secondary Tank Sludge (1 Part) + Digested Primary Tank Sludge (4 Parts)
Raw Secondary Tank Sludge
FeCl3 Used - Lbs. Per 100 Lbs. Dry Solids

FIG. 1.—Vacuum filteration of raw secondary settling tank sludge coagulated with $FeCl_3$. (See Table I for detail results.)

The next step in the investigation consisted in determining whether a smaller quantity of coagulant could be used and a greater capacity obtained by elutriating the sludge before filtering. This process, which has been described in detail in this JOURNAL,[2, 3] consisted of mixing the sludge with clean water in order to wash out the ammoniacal decomposition products of nitrogen compounds, allowing the solids to settle out over a period of several hours and then decanting the supernatant. By removing these decomposition products, which have been called amino-ammonia nitrogen compounds, less chemicals were required to coagulate the solids. In every instance where the sludge was elutriated, two volumes of water were mixed with one volume of sludge. The elutriation was carried out in two stages or steps. First, one volume of clean water was mixed with one volume of sludge. After the solids had settled and the water had been decanted off, another equal quantity of clean water was mixed with the sludge. The material settled a second time for decantation, and the sludge was then ready to be filtered.

Two runs were made to see how well the elutriated sludge could be dewatered. The output and the character of the cake were about the same as when unelutriated sludge was filtered. The cake production varied from 1.0 to 1.6 lb. of dry solids per square foot of filter area per hour. The moisture of the cake remained high, varying from 85.0 to 87.2 per cent. Since the amino-ammonia nitrogen had been reduced by elutriation to about 90 p.p.m., the quantity of coagulant used was less than when unelutriated sludge was filtered.

Filtering Mixtures of Primary and Secondary Settling Tank Sludges.—It was thought that perhaps a greater cake output could be obtained if the secondary settling tank sludge were mixed with digested primary settling tank solids. Before making these tests the latter material was filtered before and after elutriation so that the results could be used as a basis of comparison. When unelutriated digested primary settling tank sludge, which contained 815 p.p.m. of amino-ammonia nitrogen was filtered, a cake output of about 4.8 lb. of dry solids per square foot of filter area per hour was obtained with the use of 4 lb. of anhydrous ferric chloride per 100 lb. of dry solids in the sludge. The amino-ammonia nitrogen in this sludge after elutriation was reduced from 815 p.p.m. to about 240 p.p.m. With the use of 4 lb. of anhydrous ferric chloride the filter production was approximately 23.5 lb. of dry solids per square foot of filter area per hour.

The secondary tank sludge was then mixed with the digested primary settling tank solids in the ratio of 1 volume of the former to 4 volumes of the latter and then filtered. The cake production was increased two or three times more than the output when secondary settling tank sludge was filtered alone. A maximum capacity of 5.7 lbs. of dry solids per square foot per filter area per hour was obtained with the use of 10.7 lb. of anhydrous ferric chloride per 100 lb. of dry solids in the sludge. The moisture of the cake, which varied from 80.8 to 82.0 per cent, was somewhat less than when secondary settling tank sludge was filtered by itself.

The mixture of these two sludges was then elutriated. By this process the amino-ammonia nitrogen was reduced from 490 to about 170 p.p.m. Two filter runs were made. There was a slight reduction in the moisture of the cake and a material increase in the output of the filter. During Run No. 1 the cake output varied from 4.6 to 10.5 lb. of dry solids per square foot of filter area per hour with the use of from 3.2 to 7.5 lb. of anhydrous ferric chloride per 100 lb. of solids in the sludge. The filter output during Run No. 2 was from 35 to 40 per cent less than that of Run No. 1.

The 5-day B.O.D. of the elutriate from the secondary settling tank sludge and from the mixture of this sludge with digested primary settling

tank solids was considerably higher than the elutriate from the latter material by itself. When elutriating secondary settling tank sludge by itself, the elutriate from the first stage had a B.O.D. of 362 p.p.m. and that from the second stage was 170 p.p.m The elutriates from the mixture of secondary and primary settling tank sludges had an even higher B.O.D., being 490 p.p.m. for the first stage of elutriation and 310 p.p.m. for the second.

Coagulation With Chlorinated Copperas.—As chlorinated copperas can be obtained in Baltimore at about half the cost of ferric chloride, it was considered desirable to see how well the former chemical would coagulate the sludge. No success was had when using this chemical with either unelutriated or elutriated secondary settling tank sludge. It was impossible to get a cake that was sufficiently dry for continuous filter operation. Its average moisture from both the unelutriated and the elutriated sludge was about 89 per cent. As indicated in Table II and Figure 2, the same high filter output was obtained when dewatering primary sedimentation tank digested sludge.

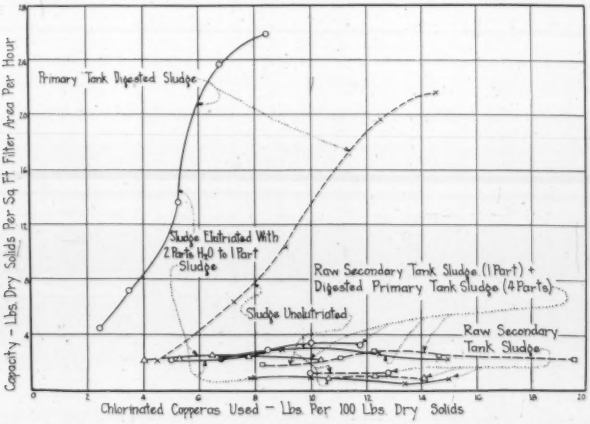
Capacity - Lbs. Dry Solids Per Sq Ft Filter Area Per Hour
Primary Tank Digested Sludge
Sludge Elutriated With 2 Parts H₂O to 1 Part Sludge
Raw Secondary Tank Sludge (1 Part) + Digested Primary Tank Sludge (4 Parts)
Sludge Unelutriated
Raw Secondary Tank Sludge
Chlorinated Copperas Used - Lbs. Per 100 Lbs. Dry Solids

FIG. 2.—Vacuum filteration of raw secondary settling tank sludge coagulated with chlorinated copperas. (See Table II for detail results.)

By filtering a mixture of one volume of secondary settling tank sludge and four volumes of digested primary tank material a drier cake and a greater output resulted. During Run Nos. 1 and 2 the quantity of cake produced varied from a minimum of 1.8 to a maximum of 3.0 lb. of dry

TABLE II.—*Vacuum Filtration of Raw Secondary Tank Sludge Coagulated with Chlorinated Copperas*

(Tests made May 2–21, 1935)

Test No.	Duration of Test,	Sludge				Anhydrous Chlorinated Copperas Used per 100 Lb. Dry Solids,	Cake		Effluent			Filter Operation	
		Solid Content,	Volatile Matter,	Amino Ammonia Nitrogen,			Dry Cake per Sq. Ft. of Filter Area per Hr.,	Moisture,	B.O.D. 5-day at 20° C.,	Suspended Solids,		Speed,	Vacuum,
	Min.	%	%	P.p.m.	pH	Lb.	Lb.	%	P.p.m.	P.p.m.	pH	Sec. per Rev.	In.
						Secondary Tank Sludge—Not Elutriated							
						Run No. 1							
1	10	3.1	71.1	210	6.1	10.6	1.0	88.2	120	51	4.3	375	15–16
2	10	3.1	75.1	220	6.1	14.1	0.9	90.4	355	148	3.8	375	15–16
3	10	3.1	75.1	220	6.1	12.3	1.0	88.3	164	72	3.9	375	16–17
						Run No. 2							
4	10	3.8	72.7	240	6.2	10.0	1.2	88.7	163	56	4.3	380	17
5	10	3.8	72.7	240	6.2	12.8	1.2	88.5	195	56	4.1	380	17
						Elutriated With 2 Parts of Water [1]							
6	10	2.7	71.0	130	6.1	10.1	1.0	86.6	176	29	4.3	375	17–19
7	10	2.7	71.0	130	6.1	15.1	0.9	86.4	203	124	3.2	375	17
8	10	2.5	72.6	130	6.1	8.0	0.9	87.4	152	31	4.0	375	17–18
9	10	2.5	72.6	130	6.1	13.4	0.5	92.1	187	90	3.2	375	17

[1] Secondary tank sludge was elutriated in 2 stages. Elutriate from 1st stage contained 1,000 p.p.m. B.O.D. (5 days at 20° C.), 300 p.p.m. suspended solids and had a pH value of 5.9. Elutriate from 2nd stage contained 600 p.p.m. B.O.D. (5 days at 20° C.), 280 p.p.m. suspended solids and had a pH value of 6.2.

TABLE II.—*Continued*

Primary Tank Sludge—Not Elutriated													
10	10	7.3	50.9	740	7.2	7.3	6.4	75.8	—	—	—	166	16
11	10	7.3	50.9	740	7.2	9.2	10.4	75.9	—	—	—	102	16–17
12	5	7.4	50.9	800	7.2	12.6	19.7	75.4	—	—	—	46	17
13	5	7.4	50.9	800	7.2	4.5	2.1	75.2	—	—	—	380	17
14	5	7.3	51.4	810	7.2	14.6	21.7	74.6	—	—	—	30	17
Elutriated With 2 Parts of Water[2]													
15	10	7.5	50.2	170	6.9	3.6	7.2	75.9	18	73	6.2	152	16–17
16	7	7.5	50.2	170	6.9	5.3	13.8	76.1	82	40	5.9	93	17
17	5	7.9	50.4	180	6.9	6.8	23.8	76.6	116	53	5.5	48	17
18	5	7.9	50.4	180	6.9	8.5	26.0	77.0	138	50	5.0	48	17
19	10	8.0	50.4	175	6.9	2.5	4.5	75.6	36	43	6.2	248	17
Secondary Tank Sludge (1 Part) and Primary Tank Digested Sludge (4 Parts)—Not Elutriated													
Run No. 1													
20	10	4.8	58.8	400	6.7	6.8	2.4	83.4	74	27	5.1	372	17
21	10	4.8	58.8	400	6.7	9.1	3.0	84.5	109	17	4.7	310	17
22	10	4.3	62.3	365	6.7	12.6	2.7	84.8	151	24	4.3	305	17–19
23	10	4.3	62.3	365	6.7	15.1	2.3	84.5	440	105	3.7	372	19
Run No. 2													
24	10	4.4	58.5	425	6.8	12.3	2.9	82.8	169	49	—	302	17–18
25	10	4.4	58.5	425	6.8	14.8	2.5	83.6	203	45	—	302	18–19
26	10	3.9	60.4	425	6.8	11.1	2.3	83.4	171	47	—	302	18
27	10	3.9	60.4	425	6.8	8.3	1.8	83.6	158	51	—	383	18
28	10	3.9	61.1	415	6.8	19.6	2.2	82.9	240	88	—	322	18–19

[2] Primary tank digested sludge was elutriated in 2 stages. Elutriate from 1st stage contained 140 p.p.m. B.O.D. (5 days at 20° C.), 264 p.p.m. suspended solids and had a pH value of 7.4. Elutriate from 2nd stage contained 120 p.p.m. B.O.D. (5 days at 20° C.), 214 p.p.m. suspended solids and had a pH value of 7.5.

TABLE II.—*Continued*

Test No.	Duration of Test,	Sludge				Anhydrous Chlorinated Copperas Used per 100 Lb. Dry Solids,	Cake		Effluent			Filter Operation	
		Solid Content,	Volatile Matter,	Amino Ammonia Nitrogen,			Dry Cake per Sq. Ft. of Filter Area per Hr.,	Moisture,	B.O.D. 5-day at 20° C.,	Suspended Solids,		Speed,	Vacuum,
	Min.	%	%	P.p.m.	pH	Lb.	Lb.	%	P.p.m.	P.p.m.	pH	Sec. per Rev.	In.
						Elutriated With 2 Parts of Water							
						Run No. 1 [3]							
29	10	4.1	61.9	190	6.3	4.0	2.2	84.2	129	10	—	285	17–18
30	10	4.1	61.9	190	6.3	5.3	2.3	84.3	107	16	—	285	17–18
31	10	4.1	61.5	190	6.3	6.5	2.5	84.0	96	20	—	285	18
32	10	4.1	61.5	190	6.3	7.8	2.4	84.1	88	10	—	285	18
33	10	4.2	61.0	190	6.4	10.4	2.3	83.7	141	41	—	285	18
						Run No. 2 [4]							
34	10	3.9	61.3	175	6.7	6.8	2.2	83.0	22	11	4.7	355	17
35	10	3.9	61.3	175	6.7	8.5	2.9	83.5	86	5	4.5	285	17
36	10	4.0	60.7	190	6.7	10.1	3.6	83.4	122	32	4.3	208	18
37	10	4.0	60.9	190	6.7	11.8	3.3	82.7	141	68	3.5	225	18
38	12	4.0	60.9	190	6.7	5.0	2.2	82.8	83	21	4.0	380	18

[3] Mixture was elutriated in 2 stages. Elutriate from 1st stage contained 875 p.p.m. B.O.D. (5 days at 20° C.) and 540 p.p.m. suspended solids. Elutriate from 2nd stage contained 410 p.p.m. B.O.D. (5 days at 20° C.), 204 p.p.m. suspended solids and had a pH value of 6.7.

[4] Mixture was elutriated in 2 stages. Elutriate from 1st stage contained 475 p.p.m. B.O.D. (5 days at 20° C.), 860 p.p.m. suspended solids and had a pH value of 6.9. Elutriate from 2nd stage contained 230 p.p.m. B.O.D. (5 days at 20° C.), 502 p.p.m. suspended solids and had a pH value of 6.8.

solids per square foot of filter area per hour. The amount of anhydrous chlorinated copperas used ranged from 6.8 to 19.6 lb. per 100 lb. of dry solids in the sludge. When the mixture was elutriated, the amino-ammonia nitrogen was reduced from about 400 to approximately 190 p.p.m. By removing these decomposition products, a satisfactory cake was obtained with the use of somewhat smaller quantities of coagulant.

Filtering Semi-Digested Secondary Tank Sludge

Some of the sludge was held from May 1, 1935, until June 18, when filtering operations were resumed. During this period there was considerable digestion of the material. The volatile matter dropped from about 75 to 67 per cent, and the pH value increased from 6.1 to 7.1. As indicated by Table III and Figure 3, this sludge after partial digestion

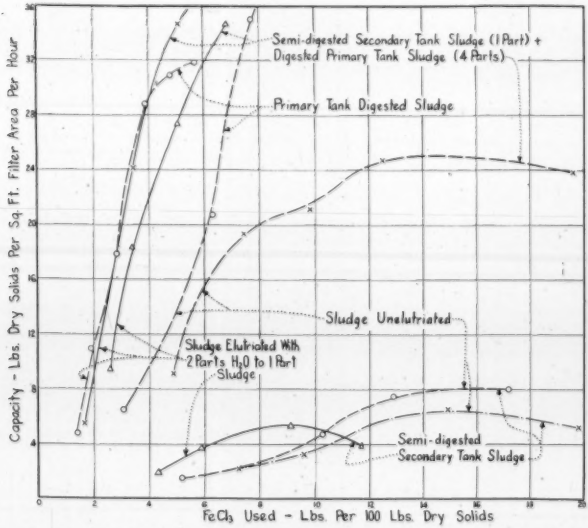
Semi-digested Secondary Tank Sludge (1 Part) + Digested Primary Tank Sludge (4 Parts)
Primary Tank Digested Sludge
Sludge Unelutriated
Sludge Elutriated With 2 Parts H_2O to 1 Part Sludge
Semi-digested Secondary Tank Sludge
Capacity - Lbs. Dry Solids Per Sq. Ft. Filter Area Per Hour
$FeCl_3$ Used - Lbs. Per 100 Lbs. Dry Solids

Fig. 3.—Vacuum filteration of semi-digested secondary settling tank sludge coagulated with $FeCl_3$. (See Table III for detail results.)

produced a much higher cake yield than the undigested material. During Run No. 1 the output varied from 2.1 to 6.5 lb. of dry solids per square foot of filter area per hour with the use of from 7.2 to 14.9 lb. of

TABLE III.—*Vacuum Filtration of Semi-digested Secondary Sludge Coagulated with $FeCl_3$*

(Tests made June 18–July 1, 1935)

Test No.	Duration of Test,	Sludge				Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids,	Cake		Effluent			Filter Operation	
		Solid Content,	Volatile Matter,	Amino Ammonia Nitrogen,	pH		Dry Cake per Sq. Ft. of Filter Area per Hr.,	Moisture,	B.O.D. 5-day at 20° C.,	Suspended Solids,	pH	Speed,	Vacuum,
	Min.	%	%	P.p.m.		Lb.	Lb.	%	P.p.m.	P.p.m.		Sec. per Rev.	In.
Secondary Tank Sludge—Not Elutriated													
Run No. 1													
1	6	3.2	66.4	400	7.1	14.9	6.5	86.2	84	71	4.3	58	15
2	10	3.2	66.4	400	7.1	19.8	5.2	87.4	146	94	4.0	95	15
3	10	3.3	67.1	410	7.1	9.6	3.2	87.7	93	47	4.7	180	15–16
4	10	3.3	67.1	410	7.1	7.2	2.1	88.3	60	71	5.9	312	15–17
Run No. 2													
5	7	3.9	60.9	500	7.0	17.2	8.0	83.9	165	90	3.1	66	15
6	7	3.9	60.9	500	7.0	12.9	7.5	84.8	148	76	3.9	66	13–14
7	10	3.2	65.2	460	7.0	10.3	4.6	85.5	77	49	4.7	174	14–15
8	10	3.2	65.2	460	7.0	5.2	1.5	88.6	46	154	6.3	300	14–15
Elutriated With 2 Parts of Water [1]													
9	9	2.7	68.0	205	6.9	11.7	3.9	86.9	95	34	4.1	102	16
10	10	2.7	68.0	205	6.9	5.9	3.7	87.1	36	7	4.8	138	15–16
11	7	2.6	68.3	200	6.9	9.1	5.3	87.1	73	10	4.8	77	15
12	10	2.6	68.3	200	6.9	4.3	1.9	87.3	20	8	6.0	300	15

[1] Secondary tank sludge was elutriated in 1 step. Elutriate contained 117 p.p.m. B.O.D. (5 days at 20° C.), 236 p.p.m. suspended solids and had a pH value of 7.0.

TABLE III.—*Continued*

Primary Tank Digested Sludge—Not Elutriated													
13	5	8.5	49.4	750	7.1	9.4	40.3	76.0	—	224	5.0	25	14
14	9	8.5	49.4	750	7.1	6.3	20.8	76.2	—	113	5.9	55	14
15	10	8.7	48.7	750	7.1	3.1	6.4	76.7	—	158	6.4	147	14–15
16	5	8.7	48.7	750	7.1	7.7	35.0	77.5	—	96	5.9	25	14–15
Elutriated With 2 Parts of Water[2]													
17	10	6.9	50.9	330	7.1	1.9	10.9	77.3	12	112	6.3	60	14–15
18	10	6.9	50.9	330	7.1	2.9	17.8	76.4	22	143	6.2	33	13–15
19	6	6.9	50.3	340	7.1	3.9	28.8	76.5	45	103	5.5	25	13–14
20	5	6.9	50.3	340	7.1	4.8	30.9	76.4	63	80	5.9	25	14–15
21	5	7.0	50.1	330	7.1	5.7	31.8	76.0	85	74	5.5	25	14–15
22	10	7.0	50.1	330	7.1	1.4	4.7	75.3	19	82	6.3	153	13–14
Secondary Tank Sludge (1 Part) and Primary Tank Digested Sludge (4 Parts)—Not Elutriated													
23	5	6.8	53.1	610	7.3	19.6	23.9	77.5	340	361	3.1	25	14–16
24	5	6.8	53.1	610	7.3	9.8	21.1	77.9	134	147	3.5	30	15
25	9	6.7	52.8	620	7.1	4.9	9.1	77.1	84	87	5.3	120	15
26	5	6.7	52.8	620	7.1	7.4	19.3	77.7	93	70	5.9	40	14–15
27	5	6.7	53.1	615	7.3	12.5	24.7	77.8	220	142	4.3	25	15

[2] Digested sludge was elutriated in 2 steps. Elutriate from 1st step contained 196 p.p.m. B.O.D. (5 days at 20° C.), 1,308 p.p.m. suspended solids and had a pH value of 7.5. Elutriate from 2nd step contained 109 p.p.m. B.O.D. (5 days at 20° C.), 544 p.p.m. suspended solids and had a pH value of 7.5.

TABLE III.—*Continued*

Test No.	Duration of Test,	Sludge				Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids,	Cake		Effluent			Filter Operation	
		Solid Content,	Volatile Matter,	Amino Ammonia Nitrogen,			Dry Cake per Sq. Ft. of Filter Area per Hr.,	Moisture,	B.O.D. 5-day at 20° C.,	Suspended Solids,		Speed,	Vacuum,
	Min.	%	%	P.p.m.	pH	Lb.	Lb.	%	P.p.m.	P.p.m.	pH	Sec. per Rev.	In.
Elutriated With 2 Parts of Water [3]													
Run No. 1													
28	6	7.7	51.8	310	6.9	3.5	24.1	77.2	60	89	5.9	26	15
29	10	7.7	51.8	310	6.9	1.7	5.5	78.0	20	108	6.2	160	15–16
30	5	7.9	51.3	280	6.9	5.1	34.7	78.9	81	92	5.6	24	15–16
31	5	7.9	51.3	280	6.9	6.8	37.7	78.6	140	79	5.2	24	15–16
Run No. 2													
32	8	7.9	49.8	310	6.9	3.4	18.4	77.4	50	96	6.1	57	14–15
33	6	7.9	49.8	310	6.9	5.1	27.4	78.7	85	76	5.7	38	14–15
34	5	7.8	49.9	315	6.9	6.8	34.7	78.6	130	118	5.1	25	15–16
35	10	7.8	49.9	315	6.9	2.6	9.4	76.9	42	54	6.1	127	15–16

[3] Mixture was elutriated in 2 steps. Elutriate from 1st step contained 106 p.p.m. B.O.D. (5 days at 20° C.), 496 p.p.m. suspended solids. Elutriate from 2nd step contained 107 p.p.m. B.O.D. (5 days at 20° C.), 516 p.p.m. suspended solids and had a pH value of 7.4.

anhydrous ferric chloride per 100 lb. of dry solids. The moisture in the cake continued high, averaging about 87 per cent. When Run No. 2 was made, digestion had progressed still further. Somewhat higher capacities with the use of smaller quantities of ferric chloride were obtained. Furthermore, the cake moisture was slightly less, amounting to approximately 86 per cent.

A portion of the sludge was elutriated with a consequent reduction in amino-ammonia nitrogen from over 400 to about 200 p.p.m. When this sludge was filtered, much smaller quantities of coagulant were required. For example, when dewatering unelutriated sludge, approximately 9.6 lb. of anhydrous ferric chloride per 100 lb. of dry solids was needed to give a yield of 4 lb. of dry solids per square foot of filter area per hour whereas this same production was obtained with the use of 6.3 lb. of coagulant when filtering elutriated material.

As in the previous tests unelutriated and elutriated primary settling tank digested sludges were filtered for comparative purposes. The cake outputs were high when dewatering both of these materials, the greater being with elutriated material.

The filter production was excellent when a mixture of semi-digested secondary tank and digested primary tank sludges was filtered. The unelutriated material, for example, gave an output of 9.1 lb. of dry solids per square foot of filter area per hour with the use of 4.9 lb. of anhydrous ferric chloride per 100 lb. of dry solids. The moisture in the cake, which was still somewhat high, averaged 77.6 per cent.

A portion of the mixture was elutriated and filtered. The elutriated solids contained approximately 300 p.p.m. of amino-ammonia nitrogen. Two runs or groups of tests were made with high outputs of cake. During Run No. 2, the production varied from 9.4 to 34.7 lb. of dry solids per square foot of filter area per hour with the use of from 2.6 to 6.8 lb. of coagulant per 100 lb. of dry solids. The moisture in the cake, which was about 78.0 per cent, was slightly higher than that in the primary digested sludge cake which averaged 76.4 per cent. The production during Run No. 1 was even higher than that of Run No. 2 with the use of smaller quantities of coagulant.

Conclusions

In the light of the experiments it seems warranted to draw the following conclusions, which apply primarily to Baltimore conditions. Since the secondary settling tank sludge at the Baltimore sewage works is normal in character, it is anticipated that similar results would be obtained at other places. This assumption, however, should not be accepted without confirming tests being made.

1. Undigested secondary settling tank sludge is much more difficult

to filter than digested primary settling tank solids. When coagulated with ferric chloride, filter capacities of about 1.0 lb. of dry solids per square foot of filter area per hour can be expected.

2. Elutriated sludge required less ferric chloride for coagulating purposes than unelutriated solids.

3. Cake moistures were considerably higher than those in digested primary tank sludge.

4. Satisfactory results were not obtained when the sludge was coagulated with chlorinated copperas. The chief difficulty was that the cake had a very high moisture content.

5. Secondary tank sludge was much easier to filter when it was semi-digested than when it was raw.

6. The best results were obtained when a mixture of semi-digested secondary tank sludge and digested primary tank solids was filtered. When this material was elutriated prior to filtration, the output was comparable with that obtained when dewatering elutriated primary settling tank digested sludge.

The Baltimore sewage works, where the experiments were conducted, are under the general supervision of B. L. Crozier, chief engineer, Department of Public Works, and George E. Finck, sewerage engineer, with G. K. Armeling, superintendent. Acknowledgments are due the Oliver United Filters, Inc., who furnished the filter and the Pennsylvania Salt Manufacturing Co., and the E. I. du Pont de Nemours and Co., who kindly furnished the coagulants. J. W. Bushman, junior chemist, assisted in the work.

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THE DISPOSAL OF SEWAGE SOLIDS*

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New procedures for the disposal of sewage solids have developed so rapidly during the past few years that one finds it difficult to determine what trends may be expected during the next few years. It seems to me that the economic depression has served to bring forth many new ideas and processes for sludge disposal, which only three or four years ago seemed to be reaching a state of standardization, if not of stagnation. Heated digestion tanks characterize the decade 1925–1935; so many plants of this character were installed during this era that we may not expect any widespread change in type of plant until the present plants require remodelling or extension. Nevertheless, there are so many new plants to be built, and some so large, that many years must pass before the need for new plants becomes satisfied; therefore there is ample opportunity to develop a new or at least greatly modified system of sludge disposal in the next few years.

Many factors have led up to the present renaissance in sludge disposal. The widespread use of the activated sludge process, the re-birth of chemical treatment, and the spur of research during the years of economic famine have initiated a new movement in sludge disposal, of which the main fruits are utilization of gas for power production, vacuum filtration of digested sludge, dewatering and incineration of undigested sludge, and an overwhelming mechanization of sludge disposal, the most important phase of sewage treatment, although formerly consigned to large structures and manual operations.

A review of what has happened during the past few years is bound to be influenced by the range of experience of the reviewer; therefore, this paper will deal in part with the developments that have taken place in the Sanitary District of Chicago and the reasons that have led up to the adoption of mechanical dewatering and incineration of undigested sludge. Concurrent research and development elsewhere will also be discussed, in order to present, if possible, an undistorted perspective of the changes and advances that have taken place so rapidly in this field.

Types of Sewage Sludge

Although there are various types of sewage sludge, such as settled, chemically precipitated, activated, or trickling filter slurry, fundamen-

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tally there are only two major types of sewage sludge—digested or undigested. Many years ago undigested sludge was found to be a gray, greasy, slimy mass that could not be dewatered, stored or dumped without the production of intolerable odors. The development of odorless methane-fermentation of sewage solids and the production of digested sludge has largely eliminated the objectionable features of undigested sludge, consequently practically all development in sludge disposal in the United States from 1910 to 1930 was based on the conviction that undigested sludge could not be disposed of without production of a nuisance. Even in the manufacture of fertilizer from activated-sludge, it seemed impossible to eliminate odors from dryers. Not until the development of odorless drying and sludge incineration has it been possible to eliminate consideration of sludge digestion in sewage treatment. Now, however, with odorless incineration possible, the way is open to safe elimination of digestion, and consequently simplification of the process of sewage treatment.

Incineration has therefore broadened the field of sludge disposal, and has provided an alternative scheme in which digestion is not essential.

The path from Imhoff tanks to separate heated digestion, to rotary heat dryers and finally to "flash drying" has been followed by the Sanitary District of Chicago through nearly five years of intensive investigations. The record of these investigations reflects the development of a new and different type of sludge disposal for the world's largest sewage disposal project, and therefore a brief review of the Sanitary District's work may be warranted. While these investigations were progressing, many studies of a different type were progressing elsewhere, such as two-stage digestion, thermophilic digestion, elutriation of digested sludge, gas utilization, spray drying and sale of dried sludge. All of these developments must be included in a record of recent progress in disposal of sewage solids.

Sludge Disposal Investigations by the Sanitary District of Chicago

Imhoff Tanks.—The Imhoff tanks operated by the Sanitary District of Chicago at the Calumet Treatment Works since 1922 have always produced a dense sludge, containing around 87 per cent moisture. Addition of activated sludge to one tank for experimental purposes resulted in a slight increase in moisture content, although not enough to require a greatly increased capacity for digestion. However, when activated sludge from the North Side Treatment Works was introduced into the Imhoff tanks at the new West Side Treatment Works in 1930, the moisture content of the digesting sludge averaged 94 per cent or higher, thus requiring very large capacities for winter storage of sludge.

In view of the large amount of activated sludge to be expected, some other means of sludge digestion or disposal was essential. Heated separate digestion was at that time (1930) the logical alternative, consequently a large and elaborate experimental plant was built for the study of separate digestion in heated tanks.

Heated Separate Digestion Tanks.—A large testing station was built at the West Side Treatment Works in 1931 for the study of separate digestion of a mixture of one part settled to one part activated sludge. The plant included: two digestion tanks 40 and 50 ft. in diameter and 35 ft. deep; two storage tanks, each 20 ft. in diameter and 35 ft. deep, built of steel; a boiler and water circulating system; and control equipment such as meters, weirs, etc. The 40-ft. tank was equipped with stirring mechanisms at top and bottom; the 50-ft. tank contained no mechanism.

This plant was operated from Aug. 4, 1931 to April 20, 1932. The results, in brief, were as follows (from Budget Report of Chief Engineer Philip Harrington, 1934):

Type of Digestion	Temp. Fahr.	Days Digestion	Sludge, Per Ct. Moisture		Gas, Cu. Ft. per Lb. Vol. Matter Added	Per Ct. Digestion of Vol. Matter	Supernatant Liquor Per Ct. Solids
			Raw	Digested			
Plain.....	94.4	28.4	96.2	96.2	8.9	42.1	0.35
Mechanical	94.8	32.0	96.1	95.5	8.9	41.9	1.37

These results, particularly with respect to the moisture content of the digested sludge, were disappointing. Storage of digested sludge was not effective in reducing the moisture content. Estimates of cost were not appreciably lower than costs of Imhoff tank operation.

As a result of this work, it was decided to carry on large-scale investigations of the dewatering and incineration of undigested sludges.

Mechanical Dewatering and Incineration of Undigested Sludge.—The first plant for mechanical dewatering and incineration of undigested sludge was built during the summer of 1932 and placed in operation August 5, 1932. The equipment consisted of a large Oliver vacuum filter, a rotary dryer 74 ft. long and 8 ft. in diameter, heated by a furnace into which the dried sludge was fed as fuel, together with additional coal as needed.

This rotary dryer was operated until May 18, 1933, when it was shut down and plans were made for construction of a differeent type of drying mechanism. The new dryers consisted of hammer mills, installed

in two stages, in the first of which the moisture of filter cake was reduced from 80 per cent to 30 per cent, and in the second stage to less than 15 per cent. This dry, pulverized sludge was blown into the furnace and burned, and the hot gases were re-circulated through a heat exchanger, thus heating the air supplied to the hammer mills. The air and vapor from the mills were separated from the sludge in cyclones, and passed through the furnace, before escape to the stack. All gases were therefore passed through a high temperature zone at 1600° F. before release, thus effectively eliminating odors.

A small amount of pulverized coal was added to the sludge before combustion.

This plant, with the four small mills, operated until late in 1934. In December, a new single cage-mill unit replaced three of the hammer mills, one being retained for coal pulverization. This new unit has shown noteworthy improvement in capacity, power consumption, and maintenance.

As a result of operation of this experimental plant, which was shut down in July, 1935, a contract has been let at the Calumet Treatment Works for a similar dewatering and incinerating plant for handling the settled and activated sludge from this plant, amounting to 40 tons of dry solids per day. This plant is under construction and will be in operation in 1936.

By this scheme of sludge disposal, it has been possible to eliminate digestion tanks and sludge beds at the Calumet Works. The same process of sludge disposal is proposed for the Southwest Side Works, now under construction. Incineration of sludge is to be used at the Southwest Side in conjunction with a coal-fired power plant. Steam is to be used in steam turbines for generation of current to operate the air blowers of the activated sludge plant. The combination of incineration and a power plant will result in marked economy in generation of electricity.

The development of the "flash-drying" system of dewatering and incineration has been under the direction of Philip Harrington, Chief Engineer, Wm. Dundas, Prin. Asst. Mechanical Engineer, the Raymond Company and others.

Concurrent Developments Elsewhere

Investigations elsewhere during the past few years have proceeded mainly toward speeding up digestion, preparing digested sludge by elutriation so that prohibitive amounts of ferric chloride will not be required for filtration, utilization of gas in gas engines with recovery of heat values, use of centrifugal machines for sludge dewatering, use of a spray dryer or a multiple-hearth furnace for drying and incineration, and disposal of sludge as a fertilizer.

Acceleration of Digestion.—Biological digestion of sewage solids is a slow process, with time periods expressed in days, weeks or months, rather than hours. Experience has shown that temperature is a very important factor in the rate of digestion, and consequently we have had extensive development in sludge heating as a means of accelerating digestion. This field has been quite thoroughly explored here and abroad, and one of the most promising developments seemed to lie in thermophilic digestion, in the range of 130° to 145° Fahrenheit. However, practical difficulties, such as odors, foul supernatant liquor, scum and slimy sludge have prevented adoption on a practical scale of thermophilic digestion, which appeared so attractive on a laboratory scale.

Recently Rudolfs and Cleary (THIS JOURNAL, 7, 781, September, 1935) have reported results of laboratory and semi-plant scale studies, in which a two-stage digestion was used, the first stage for about five days at 130° F., and the second stage for seven days at 82° F. This scheme of operation seemed to eliminate most of the difficulties formerly encountered in single-stage thermophilic digestion.

Stage digestion seems to be a step forward in sludge digestion, second only to adoption of heated tanks. Plants at Peoria, Newark, N. Y., North Toronto, and elsewhere are reported to be using this scheme successfully. The early work of Buswell (1928) at the University of Illinois should also be noted.

Probably the most noteworthy example of stage digestion is the large experimental digestion plant of the Los Angeles County Sanitation Districts. This consists of four stages of digestion, in eight rectangular tanks each 56 ft. wide by 37.5 ft. long by 15 ft. deep. The sludge passes from the bottom of each tank, under a curtain wall, to the next tank, set at a slightly lower elevation.

The feature of this plant is the return of digested sludge, from the outlet of the final tank, to the inlet of the first tank, where it is mixed with incoming sludge. The volume of digested sludge returned is about 15 to 20 per cent of the volume of fresh sludge. The temperature averages 85° F.

Remarkably good results have been reported. With a computed period of digestion of 15 days, 7.5 lb. or more of dry fresh solids were handled per cubic foot per month; the reduction of volatile solids was 53 per cent; and the gas production was estimated as equal to 1.43 cu. ft. per capita, or 6.9 cu. ft. per lb. of volatile matter added. Some scum and grit difficulties developed, but the digested sludge dried well and was free from odor.

The procedure of return of digested sludge as used in this plant seems to be worthy of further investigation elsewhere for acceleration of digestion. The analogy with return of sludge in activated sludge

operation is obvious. Likewise, the scheme of horizontal flow may prevent short-circuiting of undigested solids, and assures actual hydraulic displacement, as contrasted with the uncertain displacement and possibility of short-circuiting in vertical-type digestion tanks.

A type of digestion tank in Germany, at Hattingen, may warrant further development. This consists of an insulated horizontal cylindrical tank. Sludge is fed in at one end together with returned digested sludge. The mixture passes through the tank horizontally and digested sludge is removed at the outlet end. The sludge is heated and displacement aided by a revolving spiral pipe coil inside the tank. The feature here of interest is the return of sludge, intimate mixing and heating, and positive displacement of tank contents.

Utilization of Gas.—Utilization of gas from digesting sludge has been extended markedly during the past few years. Walraven, at Springfield, Ill. and Piatt, at Durham, N. C., have been outstanding pioneers in this development. Springfield has two gas engines of 150 and 180 h.p.; a 210 h.p. engine is in use at the new Cedar Rapids, Iowa plant; the largest in this country, a 500 h.p. unit, is being installed at Peoria, Illinois. Many smaller units are in operation throughout the United States. Data are accumulating rapidly to confirm the value of sludge gas for power production.

Dewatering of Digested Sludge.—Sand beds for dewatering digested sludge are in use almost universally at the present time, but the rapid advance of mechanical dewatering by vacuum filters presages a change in practice in the next few years. Sand beds have been extended in usefulness by greenhouse covering, although the economic advantage of the more expensive construction is not clear. For large projects, such as the Chicago West Side Treatment Works, manual labor in removing sludge from the beds has been replaced by large mechanical sludge strippers. For small plants sludge will be removed by hand as heretofore. Apparently not much more development can be expected in utilization of outdoor sand beds, and the trend of research is in other directions.

The successful filtration of activated sludge on vacuum filters directed interest toward similar treatment of digested sludge, but the cost appeared prohibitive until the last few years, mainly because of the expense for ferric chloride. At Baltimore, ferric chloride cost was 71 per cent of the total operating cost of filtration of digested sludge. Laboratory experiments elsewhere (Mohlman and Edwards, "Prefiltration Treatment of Sewage Sludge." *Ind. Eng. Chem.*, 26, 226, February, 1934) indicated that use of lime with digested sludge would permit use of a greatly reduced amount of ferric chloride, and thus effect a saving because of the relatively low cost of lime.

However, Genter and Keefer at Baltimore, in a series of admirable

research investigations, have shown that elutriation of digested sludge will effect a great reduction in ferric chloride requirement at comparatively little operating expense. With elutriated sludge, Keefer reported the cost of ferric chloride to be only 49 per cent of operating costs of filtration. It is reported that elutriation will be adopted at the new sewage treatment works at Washington, D. C., and also for extension of the Baltimore plant.

With reduction in the cost of filtration of digested sludge has come a new possibility for economical disposal of sewage solids—namely, dumping of filter cake containing 70 to 75 per cent water. This can probably be done with comparative security from odors and possibly eventual further drying of the dumped cake will occur, but as a means of final disposal of sewage solids this end product cannot be considered to be on a par with incinerated sludge or dried activated sludge. Disposal of a wet filter cake on a large scale has not yet been attempted, and only experience will determine the limitations of this procedure.

Use of Centrifugal Machines

For many years the hope has recurred that sludge, either fresh or digested, might be dewatered more cheaply and more effectively by centrifuging than by vacuum filtration. Centrifuges have been attractive because of their automatic operation and also because sludge can apparently be handled as well without conditioners as with (or, conversely, as poorly with conditioners as without). Continuous machines were investigated at Milwaukee on activated sludge, at Baltimore on digested sludge, and more recently at Collingswood, N. J., on digested sludge. Various machines of the semi-automatic type have been tested by the Sanitary District of Chicago.

The results of all of the work on centrifugals have been disappointing. Apparently the centrifugal machine is not adapted to meet the difficult requirements of sludge dewatering because of two inherent deficiencies—namely, loss of too much solid matter in the effluent and too low capacity per unit. The loss of solids in the effluent has varied from 10 to 70 per cent of the initial solids, and this cumulative recirculated loss is too great to permit continued operation. With regard to capacities, the Collingswood machine was reported to have fairly high capacity (up to 60 gal. per minute, or 800 lb. of cake with 75 per cent water per hour), but the loss of solids was excessive. A German machine used on digested sludge at Frankfort and Oslo is claimed to have a capacity of 1600 lb. of 75 per cent cake per hour, with a loss of 1.0 per cent of solids in the effluent. The machines investigated at Chicago (Evers-Sauvage, Sandis and Sharples) either failed to operate or were not considered worth further development.

Notwithstanding the record of unsuccessful attempts to use the centrifugal machine for dewatering sewage sludge, it is still possible that a successful machine may be devised. Milwaukee has installed centrifugal machines for grit and screenings, and there are several installations in Germany (Frankfurt, Hannover and Harburg).

Other Dewatering Devices

In addition to vacuum filters and centrifugal machines, the Sanitary District of Chicago has investigated various other devices for dewatering sewage sludge. These machines included a hydraulic press (Berrigan) and a paper-making machine (Beloit Iron Works). Each machine had some distinctive merit, such as low moisture content of the Berrigan cake, or high rate of operation of the paper machine, but these advantages were outweighed by certain other disadvantages, so that vacuum filters were preferred for dewatering activated sludge.

Drying and Incineration

Probably the most important recent development in disposal of sewage solids has been the investigation and use of the "flash" drying and incineration system at Chicago, and the Herreshoff furnace at Dearborn, both operating on filter cake from Oliver filters. Activated sludge is handled at Chicago and chemical sludge at Dearborn. The spray drying machine at Plainfield has operated only on sludge concentrated by flotation, and containing more than 90 per cent water.

The flash drying system has been described above. The Nichols-Herreshoff furnace has been in use since February 1935, and some details of its operation have been given by Owen (*Water Works and Sewerage*, 82, 261. August, 1935).

Nichols-Herreshoff.—The Nichols-Herreshoff incinerator at Dearborn is a six-hearth furnace 16 ft. 9 in. in diameter and 17 ft. 4 in. high. Filter cake is fed into the top and passes down from one hearth to the next alternately at the center or periphery of each hearth. Hot air passes upward through the furnace, and carries off the products of combustion and moisture. The sludge and cinder are stirred and moved from one hearth to the next by teeth or rakes attached to air-cooled rabble arms. The sludge generally dries on the first two hearths, burns on the third to fifth hearths and the ash cools on the sixth hearth. Fuel oil is supplied to burners located on hearths 1, 2 and 4. Air is preheated in a "recuperator," from which the stack gases are discharged at 900° to 1000° F.

Some of the results of operation up to the end of May, 1935, including the 90-day acceptance test, have been reported by Owen (*loc. cit.*) including estimates of cost.

The 90-day test extended from Feb. 25, 1935 to May 26, 1935. Filter cake contained an average of 66.6 per cent moisture and on the dry basis the volatile content was 50.3 per cent and B. t. u. 5450 per lb., as compared with specifications of 65 per cent moisture, 35 per cent volatile and 3500 B. t. u. per pound. Fuel oil averaged 6.8 gallons per ton of dry sludge, during the time only when sludge was incinerated, which averaged 14 hours per day during the 90-day test.

Cost estimates are presented by Mr. Owen, based on continuous operation at full capacity (17.5 tons dry sludge per day).

Undoubtedly there is considerable interest in comparison of cost data for the several incineration processes now available, and primarily between the Nichols-Herreshoff and the flash-drying types of incineration, but any such comparison would necessarily be quite involved and beyond the scope of this paper. The basic assumptions are quite different, since chemical sludge of 65 per cent moisture content is handled at Dearborn and activated sludge cake of 80 per cent moisture content at Chicago. The characteristics of the two types of sludges are quite different. Efficient utilization of heat values is probably of greatest importance. The tonnage to be handled, space required and flexibility of operation are other factors that must be considered.

Fertilizer Production.—One attractive feature of sludge drying and incineration, particularly with activated sludge, is the possibility of diverting some or all of the dried sludge, when economic conditions warrant, and selling the dried material as fertilizer. The value of activated sludge as a fertilizer is well established by the work at Milwaukee and if the costs of production can be lowered sufficiently, production and sale of sludge may warrant further development elsewhere. Sale of dried digested sludge as fertilizer appears much less attractive, because of the low-grade product. Notwithstanding the low value, it has been demonstrated at Dayton and Grand Rapids that the dried sludge can be sold at an attractive price if it is prepared in an attractive form and is sold locally without the burden of freight costs.

Rotary heat dryers have been used at Dayton and Grand Rapids, but in the work of Downes and Riley at Plainfield, N. J. a spray dryer has been used. Downes reports that, selecting a sludge with 10 per cent solids as practical for a cost calculation, and conservatively estimating an evaporation of 8 lb. of water per lb. of coal, as demonstrated by a large number of runs of from 6 to 9 hours, the cost of dewatering and drying one ton of sludge (dry basis) from digested sludge at 5 per cent solids to the product containing 70 per cent solids is $12.04, not including fixed charges. Downes states he has had no trouble getting $10.00 per ton for the sludge containing 70 per cent solids; also that the product containing more than 70 per cent solids is rather dusty to handle and

would be avoided in ordinary operation except to meet definite market requirements.

Spray drying thus seems to be limited either to a rather moist product, which may become moldy on storage, or to a fine dusty material if dried below 10 per cent moisture. Likewise no work has as yet been reported on spinning a filter cake in the bowl atomizer. Further work may therefore be advisable for development of spray drying in general. At Plainfield Mr. Downes has succeeded in keeping the drying unit in regular use, drying all the digested sludge from the sewage contributed by 50,000 persons, and operating 9 hours per day on 6 days of the week.

Incineration or Fertilizer Production.—If dewatering and drying apparatus permit either incineration or fertilizer production, it may be possible to recover, by selective screening, the richest part of the sludge for fertilizer, and to burn what is left. For example, one of a number of screening tests on the sludge from the flash dryer at Chicago gave the following results:

SCREENING TESTS ON DRIED SLUDGE

Flash Dryer, West Side Treatment Works
June 25, 1935

Retained on Mesh	Per Ct. by Wt.	Per Ct. Volatile	Per Ct. NH_3	Per Ct. NH_3 in Volatile
20	3.6	69.7	4.35	6.25
40	7.8	63.8	4.78	7.48
60	26.5	59.8	5.10	8.54
80	41.5	58.3	5.21	8.94
100	5.2	59.1	5.36	9.07
Through 100	15.4	56.3	5.05	8.95
	Wtd. Avg.		5.10	

The product coarser than 40-mesh contained comparatively large amounts of straw, fibers and splinters low in fertilizer value but high in combustibility; this material could be burned, and likewise the dusty material passing the 100 mesh screen, while the intermediate screen fractions could be diverted as fertilizer.

DISPOSAL OF SCREENINGS AND GRIT

During the recent period of development of new processes of sludge disposal, there has also been considerable thought given to disposal of screenings and grit, and as a result of this attention we now have available several improved methods for disposal of these types of solids.

Screenings and grit comprise a comparatively small proportion of the solids present in sewage, but if they are not handled correctly they may give rise to serious nuisance in a sewage treatment works.

Screenings are burned in incinerators in a number of recent plants (Aurora, Ill., Westchester County, N. Y., Milwaukee, Lancaster, Pa.), while in other plants (Baltimore, Chicago North Side, Rockford, Ill.) screenings are mechanically removed from the racks, ground in hammermills, and returned to the sewage. Another means of disposing of screenings is the so-called "comminutor," or revolving slotted screen, with vertical shaft, set below the water surface. Screenings are shredded by cutting teeth fixed to the rotor. The shredded particles pass through the screen slots and are handled in the primary settling tanks. These devices have been installed at Durham, N. C., Oklahoma City, Monroe, Wis., and elsewhere.

The removal from sight and smell of obnoxious screenings is a very practical advance in the handling of sewage solids. Grit has also frequently been objectionable because of the presence of an excessive amount of organic matter, but improved methods of washing, by means of spiral screws, classifiers, bowl washers and aeration, are now available for preventing the discharge and dumping of foul, putrescible grit.

Conclusions

Noteworthy advances have been made during the past few years in the development of methods of disposal of sewage solids. The most important development has been the adoption of incineration as a means of disposal of undigested sewage solids. Incineration makes possible the elimination of digestion, and offers an alternative to fertilizer production in the disposal of activated sludge. Incineration also has been adopted for disposal of chemically precipitated sludge. Sludge cake formerly dumped with 65 per cent water content at Dearborn is now incinerated.

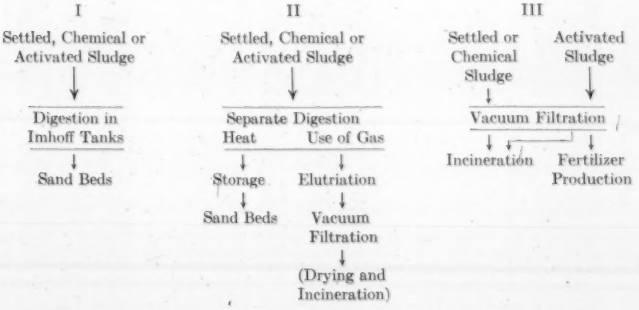
The development of flash drying and incineration at the Sanitary District of Chicago followed extensive investigations of other methods of disposal of sewage solids, including Imhoff tanks, heated separate digestion tanks, sand drying beds, vacuum filters and various types of dewatering machines. Incineration was adopted because it (1) eliminated digestion; (2) made possible the disposal of solids on a comparatively small area, as compared with the enormous area of sand beds that would be required with digestion; (3) accomplished the most complete and most sanitary method of disposal of sewage solids; (4) made possible the operation of a power plant, operating on incinerated sludge plus additional fuel, for production of power needed for operation of the activated sludge process and (5) was the most economical of all processes investigated for the disposal of sludge.

While incineration was being developed at Chicago, advances were noted elsewhere in improvement of digestion. These advances included two-stage digestion, thermophilic digestion, utilization of gas,

return of digested sludge for seeding fresh sludge, and improvement of the design of digestion tanks.

The vacuum filtration of digested sludge was made more attractive by elutriation, resulting in reduction of the requirement of ferric chloride and more rapid rates of filtration. As a result of these improvements, it has been recommended in several large treatment projects (Washington, New York, Baltimore, Columbus) that digested sludge be filtered and the filter cake dumped on waste land. This appears to be only a partial solution of the sludge disposal problem, and not so complete nor desirable as incineration.

The various alternative schemes now available for the disposal of sewage solids (excluding dumping at sea) may be broadly classified as follows:



With these various fundamental schemes available for disposal of sewage solids, the designer of new plants can adopt the plan that appears to be best suited to local conditions, without being bound to only one possible method of disposal; the wide-awake plant operator now can consider various alternatives available for plant extensions; and the research man or student of sewage treatment has available a wide field for the development of new ideas in the disposal of sewage solids.

MULTIPLICATION OF TOTAL BACTERIA AND B. COLI AFTER SEWAGE CHLORINATION *

By Willem Rudolfs and H. W. Gehm

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Until recently it has been assumed that in order to kill bacteria in sewage, residual chlorine must be present. Rudolfs and Ziemba (1) found that bacterial reductions (total organisms and *B. coli*) were obtained with partial chlorination of sewage and that the percentage reductions varied with the per cent satisfaction of the chlorine demand. The contact time allowed and the quantity of chlorine added were of importance. With lower chlorine demands of sewage the rate of kill was greater. The chloro-products formed by addition of a number of substances affected the bacterial reduction to a greater extent with increasing contact time.

The reduction in numbers of total bacteria by a bactericidal substance, followed by an enormous rise in numbers after continued incubation is known to occur in soil and water. Similar increases in sewage after the use of disinfectants have been reported, but no results seem to be available on aftergrowths in partially chlorinated sewage, or the relation between bacterial aftergrowth and protozoa in partially chlorinated sewage.

Procedure.—Cotton filtered sewage was chlorinated to 0, 25, 50, 75, and 100 per cent of the chlorine demand. After ten minutes contact time, sodium thiosulphate was added to halt the action of the chlorine. *B. coli*, total bacteria, and total protozoa were determined. Samples representing each degree of treatment were incubated at 20° C. A sample of each was removed every 24 hours following treatment and the above determinations made after thorough shaking. Series were run for three and four days.

The *B. coli* were enumerated by the brilliant-green bile tube method using three duplicates. The forty-eight hour count on plain agar was used to estimate the total numbers present.

Results.—As an example of the information obtained the results on total 20° C. bacteria present in a septic sewage, with a chlorine demand of 9.4 p.p.m., and the results on a sewage containing trade waste with a chlorine demand of 13.8 p.p.m., are shown in Table I. It is apparent that the numbers increased rapidly after a short lag period. A type curve constructed from a number of different samples collected at different places is shown in Fig. 1. It is interesting to note that with increased

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J.

TABLE I.—*Total Bacteria After Chlorination (Thousands per C.C.)*

Cl_2 Added	Cl_2 Demand Satisfied	Time (Hours)				
		0	24	48	72	96
P.P.M.	%					
0	0	5,000	8,000	6,000	1,600	400
2.4	25	4,000	15,000	30,000	5,000	1,500
4.7	50	300	21,000	50,000	20,000	3,000
7.1	75	40	26,000	50,000	50,000	18,000
9.4	100	5	25,000	50,000	53,000	20,000
0	0	1,500	25,000	30,000	7,500	
3.5	25	1,000	23,500	30,000	15,000	
6.9	50	100	13,000	18,000	20,000	
10.4	75	20	5,500	15,000	50,000	
13.8	100	5	2,000	32,000	60,000	

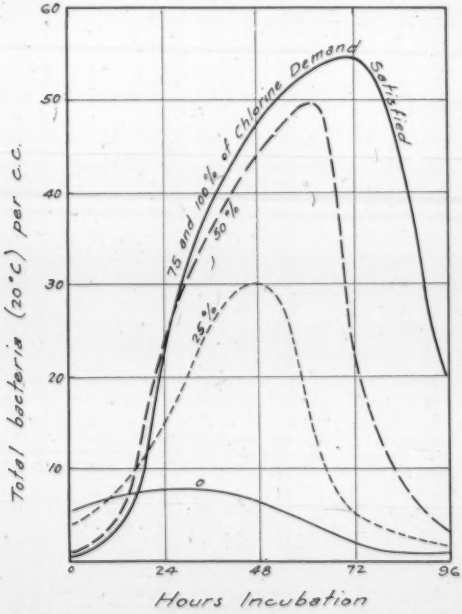

FIG. 1.—Type curves for growth of bacteria after partial and complete chlorination of sewage.

quantities of chlorine the peak of the aftergrowth becomes persistently higher, and that the time required to reach the peak is longer. Examination and plotting of a large number of results to determine whether the shift of the peak, or the time required to produce a peak (lag), was in proportion to the quantity of chlorine added, indicated that other factors also played a role. When the aftergrowth is plotted against the amount of chlorine added the usual S-growth curve is produced (Fig. 2). This holds also where the peak of the curves produced after chlorination to different percentages chlorine satisfaction are plotted against time. In all cases, except when 100 per cent of the chlorine demand was satisfied, rate of growth increased within 6 hours after chlorination, but none reached the original numbers until after 24 hours of incubation. Aeration of the sewage after chlorination decreased the lag period.

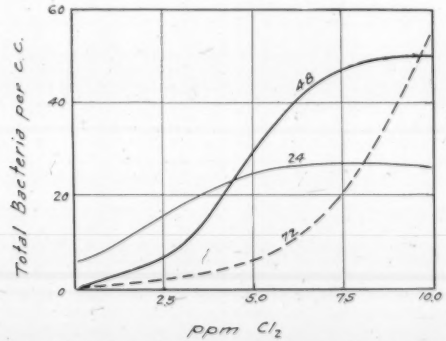

FIG. 2.—Relation between bacterial aftergrowth and amount of chlorine added to sewage.

The great rise in total numbers after chlorination has been attributed in part to the high removal of the fauna which feed on bacteria. The protozoan numbers are reduced to a greater extent by the germicide, due to their lower initial population and greater sensitivity to the germicide. Their lag period before rapid reproduction is therefore, longer than that of the bacteria. Thus the bacterial population is allowed to increase unhampered by the fauna, and reaches higher levels than when the larger organisms are present, as is the case in untreated sewage. The results obtained show this relationship quite clearly. Two examples are shown in Table 1.

The results do not preclude other possibilities. Chlorine-resistant bacteria, whose normal population level is higher than the population level of the mixed flora of sewage, with identical food conditions, may be

partially responsible for the high numbers obtained. It has been shown by Butterfield and Purdy (2) that certain bacteria attain a higher population than others, with a given amount of food. This may be due to a difference in size of organisms or efficiency of energy utilization.

Microscopic examination of the sewage showed that with 50 to 75 per cent of the chlorine demand satisfied, the protozoa were reduced to such an extent that none of these organisms were present after 72 hours of incubation. Concentration of 100 cc. portions of the 100 per cent treated samples showed but very few, if any, protozoa present after 72 hours incubation.

During the period of highest population level in chlorinated sewage, there is no increase in carbon oxidation over unchlorinated sewage. This might be construed as evidence that the flora established after chlorination has a lower energy utilization level than the mixed flora of untreated sewage. The plates of chlorinated sewages showed also a predominance of the *pseudomonas* pigment-forming bacteria, which were not evident on the plates with untreated sewage. These organisms are known to be chlorine resistant. This selective action of chlorine has been demonstrated by Charlton (3) on chlorinated water and by us on chlorinated sewage. It appears therefore, that more than one factor is involved in bacterial activity after chlorine treatment.

The *B. coli* present in sewage also reproduce after their numbers are reduced by chlorine. With complete chlorination their numbers are reduced to such an extent that they rarely return in numbers greater than those originally present in sewage. This we believe to be due to the depletion of food by the other organisms during the longer lag period of the

TABLE II.—*Recovery of B. Coli after Chlorination* (*Organisms per C.C.*)

Hours	0	24	48	72
	6	25	6,000	18,000
Reduced to	3	60	600	8,000
Less Than	2	90	400	4,500
10 per C.C.	1	40	200	400
	1	3	400	25,000
To Less Than 100	40	250	250,000	400,000
but More Than	45	450	9,500	25,000
10 per C.C.	90	1,500	45,000	—
	200	110,000	250,000	2,500,000
To Less Than	500	25,000	60,000	—
5000 but	1,400	1,100,000	1,000,000	950,000
More Than	2,500	1,100,000	1,700,000	2,500,000
100 per C.C.	4,500	95,000	300,000	450,000
	4,500	1,100,000	1,500,000	2,500,000

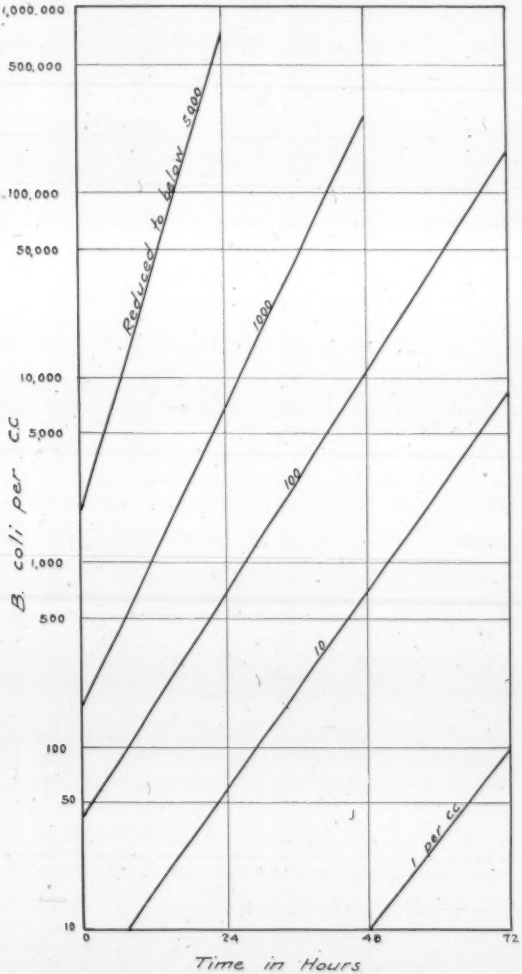

FIG. 3.—Multiplication rates of *B. coli* in sewage after reduction of numbers with chlorine.

B. coli. When small amounts of chlorine are used a tendency is noted to increase to a greater extent, due to the fact that the greater percentage of the original numbers remained, and therefore those which remained could multiply rapidly and compete better with other organisms. In those cases where the lag was somewhat longer than that of the total organisms, the multiplication of the *B. coli* came at a time when the fauna had not as yet recovered, so that unbalanced conditions still existed. The greater the initial reduction of *B. coli* by chlorination, the longer the lag, followed by a more rapid increase.

The mass of data obtained can not be presented in its entirety and an arbitrary grouping of some results is given in Table II, where the multiplication of *B. coli*, reduced by chlorination to less than 10 per cc., more than 10 but less than 100 per cc., and more than 100 but less than 5000 per cc., is shown. When the original organisms were reduced to less than one per cc., at least 48 hrs. elapsed before *B. coli* appeared in any of three 1 cc. portions inoculated.

Due to the fact that a number of different sewages, obtained from different places and under different conditions, were used, a number of apparent irregularities on the multiplication occurred. Averaging all results would be fallacious, due to the wide variation in initial populations, and for that reason type curves to summarize the information obtained are presented. A set of type curves for *B. coli* is shown in Fig. 3. The multiplication rates of *B. coli* in sewage, after reduction of numbers by chlorination, indicate the relationship between the numbers surviving and the length of time required to produce the peak level population.

Summary

Bacterial removal (*B. coli* and 20° count) from sewage varies with the quantity of chlorine added, the contact time employed, and the types of substances present. The reduction in numbers of organisms, both *B. coli* and total bacteria, was followed by great increases after incubation. In all cases, except when 100 per cent of the chlorine demand was satisfied, growth occurred within 6 hours after chlorination, but no counts reached the original numbers until after 24 hours of incubation. The aftergrowth was not directly proportional to the quantities of chlorine added. With 50 to 75 per cent of the chlorine satisfied, the fauna was reduced to such an extent that no protozoa were present after 72 hours incubation. The greater the initial reduction of *B. coli* and total bacteria, the longer was the lag, followed by a more rapid increase.

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Plant Operation

CHEMICAL TREATMENT OF SEWAGE*

REPORT OF COMMITTEE ON SEWAGE DISPOSAL AMERICAN PUBLIC HEALTH ASSOCIATION

Public Health Engineering Section

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Presented at the Sixty-fourth Annual Meeting in Milwaukee, Wisconsin, October 8, 1935

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The purpose of this Committee Report, "Chemical Treatment of Sewage," is to assemble available data, so far as practicable, relating to the use of chemicals in sewage treatment. The Committee believes that a clear presentation of the principles involved and the facts as ascertained by various workers will enlighten many laymen, doctors and engineers who are not familiar with the history of sewage treatment or the basic principles involved.

In developing this report, the Committee has purposely omitted, in general, a discussion of the use of chlorine, believing that its report on "Chlorination of Sewage," made to the A. P. H. A. in 1933, covers that subject sufficiently for the present. Those interested in ascertaining the current developments should consult the excellent report of the Committee on Research of the Federation of Sewage Works Associations, published annually in the March issue of the SEWAGE WORKS JOURNAL.

No original research has been attempted. Acknowledgment is made freely to all sources quoted for whatever appeared of value for this report. From the many articles, reports and books written on this subject and the patents taken out over a period of 80 years or more, much of interest has been gleaned, conflicting views have been analyzed and rational lines of thought indicated.

This report illustrates the swings of the pendulum of change in mode of sewage treatment, passing from the early enthusiasm for chemical treatment to biological methods and again to chemicals, a trend which now appears to be developing into a more sane appraisal of the function and scope of chemical treatment. In view of the large and generous interest among laymen, the timely comment of Potter may be noted (1):

> "The search for a chemical that will completely deodorize, stabilize and purify sewage belongs in the same category as the search for the Fountain of Youth."

and further that

> "Chemical treatment of sewage will probably reach its greatest development when its limitations are definitely established."

History of Chemical Treatment

There have been many plans, systems and patents for the chemical treatment of sewage since it was first tried in Paris in 1740. Boulnois states that more than 400 patents were issued between 1865 and 1875, few of which had much practical value (2):

The early days of chemical treatment in England are described by Dunbar (3):

"*Chemical Treatment of Sewage.*—The Commissions appointed by the Government had all recommended land treatment of sewage, but at an early date private individuals had urged the advantages of chemical treatment. Government experts had repeatedly condemned the various chemical methods as insufficient." Austin, the Chief Inspector of the General Board of Health, recommended in 1857, "the preparation of a compost from the solid matters separated from sewage by the use of precipitants, of which he mentions lime, either alone or used in conjunction with sulphate of alumina, sulphate of iron, burnt magnesia, animal charcoal, etc. He regarded the action of chemical precipitants as simply an aid to the separation of suspended matter from the sewage, and was of the opinion that these suspended matters should be removed from the sewage before its application to land."

"A report of 1864 states that neither mechanical or chemical methods can render sewage non-putrescible. These methods of treatment may yield a perfectly clear effluent, which is nevertheless capable of causing serious nuisance."

"It will be seen from the above that, almost as soon as the sewage question arose, the Government experts adopted the standpoint which has been maintained practically unchanged to the present day (1908). These views were not shared by the local authorities, many of whom were misled by the active propagandism of chemical methods of sewage treatment and utilisation. As soon as the inefficacy of one particular chemical treatment was realized, any new method which happened to be to the fore at the time was adopted. Thus it comes about that almost every large town in England can boast of having put to a practical test a whole series of chemical methods for sewage purification and utilisation."

Dunbar further notes (4):

"With regard to the purification produced, precipitation processes have again and again given rise to disappointment. The splendid results obtained in laboratory experiments and specially-constructed experimental works led the authorities of English towns to persevere with experiments. Salford has at different times tried thirteen different methods, Birmingham seven, and almost every large English town can boast of a similar experience." About 1888 "following the example of England, a few German towns adopted chemical precipitation. In every case, however, the opinion of the English Commission was confirmed, to the effect that chemical precipitation effected a satisfactory removal of the suspended matters, but yielded a putrescible effluent, which deposited solid matters in the bed of the stream; that the process was very expensive, and produced much larger quantities of sludge than were yielded by sedimentation. The sludge was practically unsaleable, and thus, owing to the putrescent character, the rapidly growing sludge-tips were a menace to the neighborhood. The sludge question became a bugbear, which was partially overcome by the introduction of sludge presses, which were first used at Aylesbury, then at Merton, and Wimbledon (1884), and at the present day (1908) are to be found at almost every sewage works. The presses convert the sludge into solid cakes, which are at least transportable. Hopes of utilising the sludge with the aid of sludge presses have not, however, been realized."

Kinnicutt, Winslow and Pratt state (5):

"The failure of sedimentation to clarify sewage thoroughly and the hope of financial gain led to the introduction in England, during the early sixties, of what is known as the chemical treatment of sewage. It was claimed that by this method the putrefactive substances in sewage would be removed and that the nitrogeneous compounds being precipitated, the sale of this precipitated matter as a fertilizer would pay for the cost of treatment and realize a substantial profit. The process was at first greeted on all sides as a method which would solve the sewage problem, and between 1880 and 1890 nearly all the plants installed in England were chemical precipitation plants."

"The hope of financial gain, however, was not realized, for though the precipitate contained nitrogenous compounds and a certain amount of phosphate, it also contained so much water, averaging about 94 per cent, that it was found impossible to prepare a marketable product at a cost at all comparable with the price of other chemical fertilizers. Further, it was also slowly recognized that though the process yielded a clear liquid, the liquid contained a large amount of soluble organic matter and was putrescible."

Among the German cities adopting chemical precipitation about 1895 were Frankfort-on-the Main and Wiesbaden. Both have since abandoned the procedure.

State of Knowledge in 1893–1894.—Santo Crimp said in 1894 (6):

"The solution of the sewage problem, so far as the employment of chemicals is concerned, is now placed upon a satisfactory basis, since the vast number of failures or negative results which have been obtained in the use of chemicals have served to reduce the question to one of comparative simplicity."

Dr. Dupre (7) added that

"as regards processes of precipitation, no proportion of chemicals which can practically be employed will do much more than clarify the sewage. Hence, the proportion of chemicals employed should be kept as low as is consistent with the object to be attained, namely, clarification."

Wardle (8) mentions, in 1893, among the best known methods:

Lime process or (Higg's): Use of 15 or more grains of milk of lime per Imp. Gal. of sewage, as at Salford.
Northampton: Use of lime (12 bushels) and 6 gallons of chloride of iron per million Imp. Gal. of sewage.
Sellers' or ABC process: Alumino ferric, wood, charcoal and clay are the precipitants.
Goodall's Process (or M. and C.): Lime, refuse carbon, house ashes, soda and perchloride of lime.
Bradbury: A crude chloride of iron.
Bell: Sulphate of alumina and protosulphate of iron.
Glauber-Ferric Syndicate, Ltd.: Precipitant is ferric chloride.
Carbferalum: Alum, china clay and vitriol.
Mather and Platt: Precipitation under patents of Archbutt and Deeley. Air mixing, precipitation, reuse of sediment.
Alfesil: Use of protosulphate of iron and sulphate of alumina, also lignite carbonised and ground, put in filter.
Ozonine-Ferricum: Basic persulphate.
Amines Process: 400 lb. of herring brine and 5000 lb. of lime per mil. Imp. Gal.
Electrical Process (Webster): Electrolysis, with iron plates.

Ferozone: Welsh iron ore treated with sulphuric acid and ground to paste (mainly sulphate and magnetic oxide of iron).
Spence's Alumino Ferric: Contains about 46.7 per cent sulphate of alumina.
Spence's Magnetic System: Carbide and magnetic oxide of iron filters.
Forbes' and Prices Process: Phosphate of alumina dissolved in sulphuric or hydrochloric acid.
Hansen's Process: Use old black-ash waste.
Hille's Process: Lime, tar, chloride of magnesium.
Holden's Process: Sulphate of iron and coal dust.
General Scott's Sewage Cement Process: Lime and clay, using 1,000 lb. lime and 500 lb. clay per 400,000 Imp. Gal.
Anderson Process: Used hot saturated solution of crude sulphate of alumina; then lime and settling.
Whitehead's: Precipitant is mixture of dicalcic and monocalcic phosphates.
Hertford: Lime and chloride of lime (56 lb. per mil. Imp. Gal. of latter).
Dibden's: Lime (3.7 gr. per Imp. Gal.) and protosulphate of iron (green copperas, 1 gr. per Imp. Gal.)

Review of British Processes.—Blew (9) has recently reviewed the early British processes for chemical treatment of sewage, during the period 1860 to 1890. He concludes that iron salts and lime were most popular, and that very few really new and unique ideas have been developed that can be considered as improvements on early knowledge of the subject.

Status in 1911.—Kershaw (10) mentions among the principal chemicals in use in Great Britain in 1911 for precipitating sewage:

Lime
Alumino-ferric
Ferric sulphate
Sulphuric acid
Ferrozone
Lime and copperas (ferrous sulphate)
Lime and alumino-ferric
Alumino-ferric, blood, charcoal and clay (A. B. C. Process)
Chloride of lime.

Patent History, British

A brief survey of the British patents relating to sewage purification, made from the published abridgements (11) of patents, reveals some very interesting history. Some earlier patents are mentioned by Wardle by date (12). These are listed with the others cited, but without the yearly serial number.

The first British patent in the abridgements involving the use of chemical precipitation appears to be one issued * to Manning in 1858 (British Patent 61, 1858) for the use of still liquors, obtained in the manufacture of chlorine from manganese ores and hydrochloric acid, used for

* On British patents cited the final number refers to the year of issue.

clarifying sewage. This was followed by Blyth (British Patent 287, 1858), who proposed the use of magnesium superphosphate in combination with lime, soda, or other alkaline material. Iron was suggested in place of magnesium, which, as treated, would be ferrous sulphate or ferrous chloride.

Some of the early British patents are remarkable for the multitude of materials in the mixture, as in the patent of Sillar, Sillar and Wigner (1954, 1868), who specified a mixture containing clay, alum, blood, magnesia or a magnesium salt, potassium manganate or other manganese compound, burnt clay or ballast, chloride of sodium, animal charcoal, vegetable charcoal and magnesium limestone.

To summarize the use of various materials added to sewage for its treatment, the following classification has been made of the earlier British patents, specifying the precipitant under which the patent number is listed herein.

Use of Salts:

Alumina Sulphate: Anderson 3,550, 1869; Bardwell 3,115, 1864 (Chemical precipitation followed by upward filtration).
Alumina Phosphate: Forbes 607, 1870; Forbes and Price 1,137, 1870.
Ferrous Sulphate: DeBossieu, 1762; Briant, 1824; Blythe 287, 1858; Bardwell 3,115, 1864; Scott, 2,808, 1865.
Ferrous Chloride: Blythe 287, 1858.
Ferric Chloride: Bardwell, 3,115, 1864.
Ferric Chlorides and Sulphates: Mackay, 91, 1875.
Mixed Chlorides of Iron: Dales, 2,157, 1857. (Dissolved magnetic oxide of iron in HCl.)
Bleaching Powder and Iron: Tanner, 9,063, 14,642, 1893.
Ferric Sulphate: Baronnet, 1845; Goodall, 848, 1826, 1874.
Ferrous Sulphate: Scott, 2,808, 1865; Burrow, 2,659, 1871.
Ferric Chloride: Jacobsen, 2,455, 1873; Harvey, 6,994, 1899.
Lime and Magnesium Chloride: Hille, 484, 1872.
Zinc Chloride: Hille, 3,167, 1870.
Zinc Sulphate: Sherwin and Sutton, 297, 1871.
Zinc Salts and Lime: Scott, 154, 1873; Jacobsen, 2,455, 1873.

Use of Acids:

Hydrochloric and Sulphuric: Schmersahl, 160, 1874.
Sulphur Dioxide: Rawson, Sillar, Slater and Wilson, 2,662, 1873.
Phosphoric Acid (or Soluble Salts) plus Lime: Prentice, 2,919, 1868.

Use of Insoluble Material:

Clay: Parry and Frearson, 579, 1867; Hart and Parry, 788, 1867; Smith and Bazalgette, 3,562, 1868; Slater, 3,095, 1876.
Infusorial Earth: Slater, 3,095, 1876.
Lignite: Bonneville, 2,926, 1866.
Marl: Smith and Bazalgette, 3,562, 1868.
Paper: Bock, 3,252, 1883.
Peat: Hays. 2,297, 1870; Robey, 2,534, 1873; Schmidt, 9,338, 1894.

Pre-Sedimentation.—The settling of sewage prior to chemical treatment appears in a number of British patents. Manning (British Patent 1,343, 1860) proposed to allow the sewage to settle in tanks, draw off the water and add to it as a precipitant and deodorant alum sludge or aluminum sulphate, sulphuric acid and ferric oxide or other material.

Scott (British Patent 4,305, 1874) proposed to remove suspended matter by settling in tanks, or by filtration, or by combined settling and filtration, and to treat the effluent with milk of lime, with further treatment.

Nicholls (British Patent 1,337, 1888, proposed pre-settling prior to addition of precipitating agents.

Adeney and Parry (British Patent 3,312, 1890) proposed first a settling tank, and then a mixing tank, using ferric or ferrous chloride to deodorize hydrogen sulphide.

Use of Paper.—Of interest is a patent issued to Bock (No. 3,252, 1883) as follows:

> "Fibrous matter, consisting of wood pulp, paper pulp, fibriferous mud or sludge itself, if fibrous, is used as a precipitant in conjunction with iron and magnesium chloride or other salts, or iron oxides, with soda or other alkali and milk of lime. The sludge, after settlement, is used to precipitate a fresh charge of sewage, with or without additional precipitant. The effluent is filtered through a Purvez trough filter, deodorized with alkaline manganate and treated with sulphurous acid in order to form calcium bisulphite to kill the microbes. The sludge is pressed, dried and used for manure."

Re-use of Sludge as a Precipitant.—The re-use of previously precipitated material as a precipitant appears in a number of British patents. Sillar and Wigner (British Patent 1954, 1868) claim the accumulated sediment from precipitation may be used as a precipitant for another portion of sewage. This re-use of sludge appears again in Jacobsen, 2455, 1873, and in Bock (with or without additional precipitant) in 3252, 1883. The re-use of sludge also appears in a number of patents issued to Archbutt and Deeley (13) both on a fill-and-draw and a continuous procedure.

Archbutt and Deeley (British Patent 19,830, 1892) claim that the blowing up of mud (previously precipitated sludge) accelerates deposition of freshly formed precipitate in both sewage treatment and water softening on a fill-and-draw basis.

Patent History, United States

The most important United States patents relating to the chemical treatment of sewage are listed in Appendix A. Many of these patents will also be found in Great Britain. For ease of reference, certain patents have been listed in Table I to show those corresponding to various processes as commonly designated.

TABLE I.—*Chemical Processes Operated in Recent Years on Sewage U. S. Patents Relating Thereto*

Name of Process or Patentee	U. S. Patent		Chemicals or Solids Used
	Serial No.	Date	
Laughlin	1,877,622	9–13–1932	$FeCl_3$ or $Fe_2(SO_4)_3$; CaO, paper pulp, Cl_2
Guggenheim (Gleason and Loonam)	1,886,267	4–18–1932	$Fe_2(SO_4)_3$; CaO; Zeolite; NaCl for Zeolite; H_2SO_4 for ash
Guggenheim (Gleason and Loonam)	1,956,420	4–24–1934	$Fe_2(SO_4)_3$; CaO
Travers	1,440,253	12–26–1922	Marl; CaO; $FeSO_4$
	1,672,584	6– 5–1928	Waste cement mfr. dust; CaO; $FeSO_4$
	1,672,585	6– 5–1928	Waste matter mfr. Cl. bleaching powder or caustic soda; CaO or $FeSO_4$
	1,672,587	6– 5–1928	CaO; $CaSO_4$; $FeSO_4$; etc.
	1,715,877	6– 4–1929	$Ca(OH)_2$ and $CaCO_3$
	1,747,803	2–18–1930	
Diamond Alkali Co. (Windecker)	1,968,114	7–31–1934	Cl_2 and CaO
Stevenson	1,946,818	2–13–1934	Regeneration of coagulants with Cl
Landreth	1,139,778	5–18–1915	CaO (Electric current)
	1,364,387	1–14–1921	
	1,507,121	9– 2–1924	
Wright (Raisch and Wright)	1,937,481	11–28–1933	Paper pulp and CaO (Filtering sewage through a mat on vacuum filter)
Koller and Miller	1,997,302	4– 9–1935	CaO; $CuSO_4$; Na_2CO_3; $Na_2Al_2O_4$; Cl_2
Putnam	1,915,240	6–20–1933	$FeCl_3$; CaO; charred sludge
Miles	1,134,280	4– 6–1915	H_2SO_4 or SO_2
Ornstein	1,904,246	4–18–1933	Sedimentation prior to chemical precipitation; digestion of chemical sludge
Langelier	1,465,137	8–14–1923	Adjustment with acid to better coagulation

Among patents not listed in Appendix A is one of Langelier (U. S. Patent 1,465,137, issued Aug. 14, 1923), in which is claimed a method of water or sewage treatment whereby an acid material is added to an alkaline liquid, together with a soluble coagulating salt, in suitable proportions to be determined by experiment.

Reactions Involved in Chemical Precipitation

The coagulants added to sewage in chemical precipitation react either with substances normally present in the sewage or with substances added for this purpose (14).

The reactions involved in chemical precipitation are taken up in the following order:

(1) Alum;
(2) Copperas and lime;
(3) Ferric sulphate and lime;
(4) Chlorinated copperas and lime;
(5) Ferric chloride;
(6) Ferric chloride and lime;
(7) Ferrous chloride and lime;
(8) Lime;
(9) Sulphuric acid and sulphur dioxide.

(1) *Alum.*—When alum is added to sewage containing in solution calcium and magnesium bicarbonate alkalinity, the reaction that occurs may be illustrated as follows:

$$Al_2(SO_4)_3.18H_2O + 3Ca(HCO_3)_2 = 3CaSO_4 + 2Al(OH)_3 + 6CO_2$$

Aluminum Sulphate. *Soluble*	Calcium Bicarbonate. *Soluble*	*Soluble*	*Insoluble*	*Soluble*

The insoluble aluminum hydroxide is formed as a bulky, gelatinous floc which settles slowly through the sewage, sweeping out suspended matter and producing other changes in the liquid. The reaction is exactly analogous when magnesium bicarbonate is substituted for the calcium salt. Since alkalinity is reported in terms of calcium carbonate ($CaCO_3$), the quantity of alkalinity required to react with 1 grain per gallon of alum is 7.7 p.p.m. If less than this amount is available for decomposing the alum, artificial alkalinity must be added. This is seldom required in sewage treatment. Lime is commonly used for this purpose where necessary.

(2) *Copperas and Lime.*—In ordinary sewages, copperas cannot be employed alone as a precipitant but lime must also be added, as will

appear from the reactions involved (15). The process is commonly spoken of as the iron and lime process.

$$FeSO_4.7H_2O + Ca(HCO_3)_2 = Fe(HCO_3)_2 + CaSO_4 + 7H_2O$$

Ferrous Sulphate. *Soluble*	Calcium Bicarbonate. *Soluble*	Ferrous Bicarbonate. *Slightly soluble*	Calcium Sulphate. *Soluble*

If lime, CaO, is now added in the form of milk of lime, $Ca(OH)_2$, the reaction that takes place is:

$$Fe(HCO_3)_2 + 2Ca(OH)_2 = Fe(OH)_2 + 2CaCO_3 + 2H_2O$$

Ferrous Bicarbonate. *Slightly soluble*	Calcium Hydroxide. *Slightly soluble*	Ferrous Hydroxide. *Very slightly soluble*	Calcium Carbonate. *Very slightly soluble*

The ferrous hydroxide is oxidized to ferric hydroxide, the final form desired, by the oxygen dissolved in the sewage:

$$4Fe(OH)_2 + O_2 + 2H_2O = 4Fe(OH)_3$$

Ferrous Hydroxide. *Very slightly soluble*	Ferric Hydroxide. *Insoluble*

A small quantity of lime is also used to neutralize the free carbonic acid in the sewage:

$$CO_2 + Ca(OH)_2 = CaCO_3 + H_2O$$

The above reactions hold if the lime added is just sufficient to neutralize the copperas and free CO_2. If a larger quantity of lime is added, there results a partial softening of the water:

$$Ca(HCO_3)_2 + Ca(OH)_2 = 2CaCO_3 + 2H_2O$$

In short form, the reactions may be expressed as:

$$FeSO_4 + Ca(OH)_2 = CaSO_4 + Fe(OH)_2$$

When oxidized by aeration or otherwise:

$$4FeSO_4 + 4Ca(OH)_2 + O_2 + 2H_2O = 4CaSO_4 + 4Fe(OH)_3$$

The insoluble ferric hydroxide is formed as a bulky, gelatinous floc similar to the alum floc. One grain per gallon (17.1 p.p.m.) of copperas requires 6.2 p.p.m. of alkalinity; 6.9 p.p.m. of lime; and 0.49 p.p.m. of oxygen. Oxidation is favored by a high pH value, which is established to some extent by the lime. The volume of air required depends on the efficiency of the aerating apparatus. Streander and Blew indicate (16) that from 1/12 to 1/8 cu. ft. per gal. are required, to provide 5.0 p.p.m. residual dissolved oxygen in a raw sewage containing no dissolved oxygen.

In sewage treatment, lime is commonly added in excess of the amount required to complete the "iron and lime" reaction, the excess lime acting as an additional clarifying agent. Since the formation of ferric hydroxide

is dependent upon the presence of dissolved oxygen, iron and lime cannot well be used with septic sewages or industrial wastes devoid of oxygen.

Ferric sulphate is a good coagulant, even without the addition of lime. Although not readily obtainable as a commercial product until recently, it is now available on the market.

(3) *Ferric Sulphate and Lime.*—The result of adding ferric sulphate and lime also leads to the production of the insoluble ferric hydroxide:

$$\underset{\textit{Soluble}}{Fe_2(SO_4)_3} + \underset{\textit{Slightly soluble}}{3Ca(OH)_2} = \underset{\textit{Soluble}}{3CaSO_4} + \underset{\textit{Insoluble}}{2Fe(OH)_3}$$

(4) *Chlorinated Copperas.*—The results of adding chlorinated copperas (that is a ferrous sulphate merged with a chlorine solution, with the production of a mixture of ferric chloride and ferric sulphate) and lime to the sewage results in precipitation of ferric hydroxide.

Potter notes (1) that chlorinated copperas as prepared is a solution theoretically containing 28.9 per cent ferric chloride and 71.1 per cent ferric sulphate. The following reaction indicates that 88.7 pounds of $FeSO_4.7H_2O$ + 11.3 pounds of Cl_2 will make 100 pounds of chlorinated copperas.

$$6FeSO_4.7H_2O + 3Cl_2 = 2FeCl_3 + 2Fe_2(SO_4)_3 + 42H_2O$$

In practice, excess chlorine is used to insure oxidation of all of the copperas.

(5) *Ferric Chloride.*—Hyde (17) points out that when ferric chloride is added to water it hydrolyzes to form ferric hydroxide and releases hydrogen and chloride ions. The hydrogen combines with the bicarbonate ion to form slightly ionized carbonic acid. The chloride ion remains in the water. The reactions may be expressed as follows:

$$(1)\quad FeCl_3 + 3H_2O = Fe(OH)_3 + 3H^+ + Cl^-$$

$$(2)\quad 3H^+ + 3HCO_3^- = 3H_2CO_3$$

(6) *Ferric Chloride and Lime.*—The addition of ferric chloride and lime to sewage result in the production of the insoluble ferric hydroxide:

$$\underset{\textit{Soluble}}{3FeCl_3} + \underset{\textit{Slightly soluble}}{3Ca(OH)_2} = \underset{\textit{Soluble}}{3CaCl_2} + \underset{\textit{Insoluble}}{2Fe(OH)_3}$$

(7) *Ferrous Chloride and Lime.*—The treatment of scrap iron with chlorinated water will produce a solution of ferrous chloride:

$$Fe + Cl_2 = FeCl_2$$

Approximately equal parts of chlorine and iron are required (16).

The addition of lime to ferrous chloride results in the production of

the soluble ferrous hydroxide. Adding oxygen to the sewage converts this to the insoluble ferric hydroxide.

$$4FeCl_2 + 4Ca(OH)_2 + O_2 = 4CaCl_2 + 4Fe(OH)_3$$

Soluble *Slightly soluble* *Soluble* *Insoluble*

The use of ferrous chloride or ferrous sulphate with lime and aeration requires longer periods of contact in the mixing and aeration tank. Blew found (16) that about 30 minutes was required to completely oxidize the ferrous sulphate in a 1 per cent solution.

(8) *Lime.*—When lime alone is added as a precipitant or is used in excess of the amount required for the precipitation of the iron in the iron and lime process, the principles of clarification are explained by the following reactions:

$$Ca(OH)_2 + H_2CO_3 = CaCO_3 + 2H_2O$$

Calcium Hydroxide. *Slightly soluble*	Carbonic Acid. *Soluble*	Calcium Carbonate. *Very slightly soluble*

$$Ca(OH)_2 + Ca(HCO_3)_2 = 2CaCO_3 + 2H_2O$$

Calcium Hydroxide. *Slightly soluble*	Calcium Bicarbonate. *Soluble*	Calcium Carbonate. *Very slightly soluble*

A sufficient quantity of lime, therefore, must be added to combine with all the free carbonic acid and with the carbonic acid of the bicarbonates to produce calcium carbonate, which acts as the coagulant. Much more lime is generally required when used alone than when sulphate of iron is also employed. Where industrial wastes introduce mineral acids or acid salts into the sewage, these must be neutralized before precipitation can take place. In some cases the sewage contains iron wastes which may then take the place of the copperas introduced artificially in the iron and lime process.

If too much lime is used in the treatment of sewage, some of the suspended organic matter will be dissolved by the caustic calcium hydroxide and the effluent may be worse than the untreated sewage. If insufficient quantities are added, the effluent will not be well clarified.

(9) *Sulphuric Acid and Sulphur Dioxide.*—Sulphuric acid or sulphur dioxide do not flocculate sewage by formation of an insoluble curd, but by neutralization of the alkalinity, according to the following reaction. The pH of the sewage is lowered to such a degree that a limited amount of flocculation occurs as the iso-electric point of the colloidal matter is

approached. This type of flocculation depends upon neutralization of the electrical charges on the sewage colloids.

$$H_2SO_4 + Ca(HCO_3)_2 = CaSO_4 + 2CO_2 + 2H_2O$$

Sulphuric Acid.	Calcium Bicarbonate.	Calcium Sulphate.	Carbon Dioxide.
Soluble	*Soluble*	*Soluble*	*Soluble*

When sulphur dioxide is used, it hydrolyzes to form sulphurous acid and reacts with the alkalinity of the sewage to form bisulphites. Both of these compounds are oxidized in the presence of dissolved oxygen. The reactions may be stated as follows:

$$2H_2SO_3 + Ca(HCO_3)_2 = Ca(HSO_3)_2 + 3CO_2 + 2H_2O$$

Soluble *Soluble* *Soluble* *Soluble*

$$SO_2 + H_2O = H_2SO_3$$

$$2H_2SO_3 + O_2 = 2H_2SO_4$$

$$Ca(HSO_3)_2 + O_2 = CaSO_4 + H_2SO_4$$

Soluble *Soluble* *Soluble*

Chemistry of Coagulation

Buswell discusses (18) at considerable length the chemistry of coagulation from the standpoint of aluminum salts applied to water filtration, commenting on the mechanism of purification reactions. He states that "reactions showing the formation of hydroxides of iron and aluminum are incorrect. These substances precipitate largely in the form of basic salts (see Ref. No. 17). The effect of sulfuric acid and sulfur dioxide is not a neutralization of electrical charges by a dehydrating effect. The difference between the two actions is of practical importance in controlling chemical treatment."

Floc Formation.—Apparently all authorities agree that the floc formation with any coagulant is related to the hydrogen ion concentration in the liquid. The economic control is thus determined in part by the pH value.

Langelier in 1921 pointed out (19) the importance of hydrogen ion concentration as a factor in coagulation of water. His tests began in 1919. Previously, in 1916, Morrison had noted (20) an optimum dosage with aluminum sulphate, in one case in which one-half the alkalinity was neutralized.

Wolman and Hannan (21) in December, 1920, conducted laboratory tests to determine what effect, if any, the pH value of water might have upon coagulation.

Miller states (22) three chemical factors which determine the optimum

conditions for floc formation in the clarification of water, by ferric salts, as with aluminum salts:

(1) There must be present in the water a certain minimum quantity of ferric ion.
(2) There must be present an anion of strong coagulating power, such as the sulphate ion.
(3) The hydrion concentration must be properly adjusted.

Bartow, Black and Sansbury note (23) that waters vary greatly with respect to optimum floc formation. Experiments on the effect of various ions, such as the sulphate, chloride or calcium ions, on floc formation with ferric salts at different pH values, seemed to show that—

(1) On the acid side of neutrality, the sulphate ion has a much greater effect upon coagulation than does the chloride ion.
(2) Little difference was noted with large variations in sulphate ion varying from 25 to 250 p.p.m.
(3) In the zone between pH 6.5 and pH 8.5, ferric floc forms slowly, if at all.
(4) In and beyond this zone, on the alkaline side of neutrality, sodium and calcium ions are most effective in coagulation.

Willcomb points out (24) that in treating sewage polluted waters, as the organic content increases the pH value at which optimum coagulation occurs decreases in like proportion. Such types of water do not seem to require violent agitation.

pH Requirements.—The efficient employment of ferrous sulphate and lime on most sewages requires appreciable aeration with a pH value of 8.4 or higher (25).

Floc Conditioning.—Hyde indicates (26) that to obtain the maximum efficiency from any coagulant, it must be properly coagulated and the largest possible masses of floc formed in the mixing chamber. Turbulent, preferably rotary motion is necessary in the conditioning chambers. Various designs of channels have been used, with baffles, rotating paddles, aeration alone or combined with mechanical stirring (26).

The period for floc conditioning varies from 20 to 30 min., after mixing, according to authorities (24, 28). Hoover indicates that from 30 to 60 minutes may be required (29). Eldredge, Mallmann and Theroux recommend slow stirring for at least 30 minutes (30). Luther (31) at Freeport, L. I. recommended 15 minutes.

The value of proper mixing and conditioning in saving in chemicals has been amply demonstrated in the water works field by Willcomb (24).

The performance of the Guggenheim apparatus in its first stage of chemical precipitation at the North Side Works of The Sanitary District of Chicago clearly demonstrated the value of thorough mixing. Where

iron salts are used, rapid and efficient mixing is essential, followed by slow motion flocculation for a period of 10 minutes or more. To preclude reduction of the iron in ferric salts and avoid indifferent coagulation (25), air blowing or prechlorination to oxidize reducing compounds in the sewage is essential.

Mixing.—The velocity of travel in mixing basins may range, for water, from 0.5 to 1.0 ft. per second (32).

Sedimentation.—In the design of sedimentation basins for coagulated sewage, much can be learned from water works practice (33, 34, 35, 36) as well as from sewage practice (37).

Period of Settling.—At Grand Rapids, Eldridge, Mallmann and Theroux consider the most effective settling period to be from 1.5 to 2 hours (30).

Pre-settling.—The value of pre-settling prior to coagulation remains to be proven. The data available are rather inconclusive. Enslow claims (25) that it has been demonstrated at Palo Alto by Stevenson and at Shades Valley, Birmingham, by Hendon. In neither case are there sufficient data or comparative tests to prove the point. Tests with controls on a laboratory scale by The Sanitary District of Chicago have not shown any significant difference in B.O.D. reductions by sedimentation prior to the application of coagulants.

Return of Sludge.—The procedure of returning sludge in a continuous process was indicated by Archbutt-Deeley in 1892 (British Patent 19,829, 1892) as useful for sewage, industrial wastes and water softening. As generally practiced in water softening or trade waste treatment, on an intermittent or batch basis, the sludge from prior operation was kept in the tank and used over (38, 13). This procedure has been utilized for years in water softening the world around by various types of softeners.

Enslow believes (25) economy results in the amount of chemicals used, and that by returning the chemical sludge and mixing it with the preliminary sludge, a mixed sludge results of moisture content more advantageous as a whole, particularly where sludge is digested. However, the tests at Palo Alto and Shades Valley at Birmingham are not conclusive as to the value of returning sludge.

Choice of Chemicals

Enslow states (25) that "there appears no practical justification for the use of anything more than the most inexpensive ferric salt and pH adjustment, if required, with a minimum of acid or lime to procure the most efficient coagulation with the least sludge production."

The choice of a coagulant depends (1) on various factors other than its basic price. Factors of importance include transportation cost, quantity required and the handling, storing and feeding requirements

and facilities. At present prices, the following limitations will be found applicable in general:

1. Some form of ferric chloride, or chlorinated copperas, will be preferable for sludge conditioning.
2. Tank car shipments of ferric chloride will be most economical for plants having siding facilities and requiring more than 7 tons of iron per year for either sludge conditioning or chemical precipitation.
3. One of the coagulants other than ferric chloride liquor should be considered for chemical precipitation plants without sidings or requiring less than 7 tons of iron per year.

Effectiveness of Chemicals.—Enslow claims (25) that in chemical precipitation all ferric salts are about equally effective on the basis of iron involved.

Ferrous Sulphate.—Ferrous sulphate (18), when treated with lime in the presence of air, forms ferrous hydroxide, which is more soluble than ferric hydroxide. A pH somewhat higher than 7.7 is required for the formation of the ferrous hydroxide. A high pH favors the oxidation of this compound to the ferric state.

In July, 1898, Bull employed (39) ferrous sulphate as a coagulant in water treatment, made by burning sulphur, passing the SO_2 gas into water and the derived sulphurous acid over scrap iron. This was tried at Lorain, Ohio. In 1903, copperas (ferrous sulphate) was put on the market by the American Steel and Wire Co. This was recovered as a by-product from iron or steel pickling liquors. Copperas is invariably used with lime and coagulation occurs after oxidation to the ferric condition.

Ferric Sulphate Coagulation.—Holton and Bean describe (40) the use and application of ferric sulphate or "Ferrisul" (approximately 94 per cent ferric sulphate) in water works practice. It is claimed that ferric sulphate is more efficacious than copperas, or chlorinated copperas, when used with lime.

Ferric Chloride.—Hyde points (41) out that the use of ferric coagulants, directly as such, in water and sewage treatment is very recent, and has developed largely in the last 3 years. Apparently the value of ferric chloride as a coagulant was recognized (42) as early as 1902. Only recently has ferric chloride been available at a reasonable price.

Ferric chloride may be had commercially in three forms, anhydrous, solid or lump, and aqueous solution.

In 1926, Mohlman and Palmer made (43) a combination of ferric sulphate and ferric chloride by passing chlorine gas into a solution of ferrous sulphate. This was primarily for conditioning sewage sludge. They also tried ferric chloride purchased commercially. This discovery

was adopted at Milwaukee for conditioning the activated sludge, and the use of ferric chloride is now almost universal for conditioning activated sludge prior to filtration.

Bull made (44) $FeCl_3$ by treating scrap iron with gaseous chlorine obtained from an electrolytic cell.

Hyde notes (45) that in water works practice with ferric chloride, floc formed satisfactorily at all temperatures, and at all pH values between 6.0 and 7.6; underdosing was unsatisfactory, but over-dosing had no deleterious effects. The floc formed was heavy and settled rapidly.

Ferric chloride is an oxidizing agent (46) and has been employed with success in treating water or sewage containing hydrogen sulphide. In treating such waters, the iron is reduced to the ferrous condition. In order to be reoxidized to the ferric condition, a high pH value is required in the presence of additional air or oxygen. This can be secured by the use of lime plus air.

Ferric chloride coagulation was used (47) at Beverly Hills, Calif. in 1932, treating water containing H_2S.

Dose of Ferric Salt.—Baumgartner has outlined (48) an experimental method for flocculating tests tried at the New Jersey Agricultural Experiment Station, with a six-place stirring machine. The averaged results of many tests under these experimental conditions at high coagulant dosages, from 15 to 35 p.p.m. ferric iron, required for complete coagulation, gave reductions in suspended solids from 90 to 95 per cent and in 5-day B.O.D. from 80 to 85 per cent. As calculated from settled controls, the reduction in non-settleable suspended solids was 80 to 85 per cent, and 5-day B.O.D. of non-settleable material, 65 to 70 per cent. These tests were on strong sewages.

The results at low chemical dosage (from 2.5 to 15 p.p.m.) and mixing for 15 to 30 min., showed variation in suspended solids reduction from 80 to 85 per cent and in 5-day B.O.D. from 70 to 75 per cent. On the basis of non-settleable content of suspended solids and B.O.D., the reductions were 60 to 65 per cent and 50 to 55 per cent. The low dosages were found to represent the most effective use of coagulant.

Baumgartner concludes:

(1) The nature and size of the greater part of non-settleable matter in sewage is such that it can be rendered settleable by treatment with small amounts of ferric salts (2.5 to 15 p.p.m. ferric iron) and mixing.

(2) In order to reduce the turbidity to 5 to 50, from 15 to 35 p.p.m. of ferric iron was required for strong domestic sewages, but the additional removal of suspended solids and reduction in B.O.D. was small.

(3) The purification secured as related to amount of coagulant added would depend chiefly on efficient mixing and sedimentation of the treated sewage.

Determination of Coagulant Dosages.—Riddick (49) details a simple home-made apparatus for determining coagulation dosage in the laboratory. The apparatus consists of a set of 8 stirrers actuated by a ceiling-fan motor. Light is admitted by a hole under the center of each beaker.

Sulphate of Alumina.—Sulphate of alumina has been used in industrial waste treatment in England for years. In most cases, Naylor notes (50), it has been made at the works from bauxite by treatment with sulphuric acid, and is used crude or after being rendered basic. At Chorley, the crude alum was used on sewage.

Use of Paper.—Waste paper has been used in amounts from 200 to 400 lb. per m.g. at Dearborn and Coney Island (51).

Activated Carbon.—As an aid to the digestion and control of odors, activated carbon is attracting attention in sewage treatment (52). The carbon is applied in dry form to a stream of water and mixed with the sewage in the sewer above the treatment plant. Split treatment is sometimes tried, half of the carbon being added to the raw sewage; the other half to the digesting sludge. The average dose has been between 35 and 50 lb. per mil. gal. of sewage. Full scale tests at Fairport, Garden City, East Rochester and Newark, N. Y., point to speeding up of digestion, increase in gas production, lessening of scum, and reduction of H_2S odor from raw sewage. East Rochester notes that no difference is found in removal of suspended solids by settling. The question of cost has not been investigated fully.

Rudolfs (53) has recently reported the results of an extensive series of research studies on the use of activated carbon in sewage treatment. The most important conclusions are that carbon has a distinct accelerating effect on digestion, but is not of much value for use in clarifying or biological processes. No cost data are given.

Reclamation of Lime.—The reclamation of lime has been proposed, as at Winston-Salem, N. C. (54). However, impurities accumulate, requiring considerable additions of fresh lime for makeup.

Commercial Handling of Chemicals

Potter (55) describes the methods of shipment of chlorine by cylinders, truck shipment of drums, multi-unit tank cars and single unit tank cars, covering weights from 97 to 60,000 lb. of chlorine (see Table II). Protection of chlorine units, methods of unloading and precautions needed are noted. Potter also discusses the handling of ferric chloride as liquor, crystals and anhydrous (see Table III), and comments on the use of chlorinated copperas and ferric sulphate. Suggestions are given as to tank protection, materials for resistance to corrosion and methods of feed.

TABLE II.—*Data on Commercial Shipment of Chlorine*

Liquid Chlorine Net Weight	Container	Approximate Overall Dimensions	Container Weight	Mode of Shipping	Recommended for Plants
100 lb. . .	Cylinder	$8\frac{1}{2}'' \times 54''$ or $10\frac{1}{2}'' \times 42''$	97 lb.	Freight, Express, * Truck	Outside of trucking area or without access to approved sidings or requiring less than 40 lb./day.
150 lb. . .	Cylinder	$10\frac{1}{2}'' \times 54''$	120 lb.	Freight, Express, * Truck	
2,000 lb. . .	Drum	$30'' \times 80''$	1,260 lb.	* Truck	Without sidings and within trucking area using more than 40 lb./day.
30,000 lb. . .	Multi-Unit Tank Car	7′ H. 10′ W. 43′ L.		Freight	With sidings using more than 200 lb./day.
32,000 lb. . .	Single Unit Tank Car	11′ H. 10′ W. 34′ L.		Freight	With sidings using more than 200 lb./day.
60,000 lb. . .	Single Unit Tank Car	13′ H. 10′ W. 35′ L.		Freight	Not recommended for sewage treatment plants.

* Interstate trucking of chlorine containers is subject to I. C. C. Regulations and is specifically prohibited in common carrier trucks.

TABLE III.—*Data on Commercial Handling of Iron Salts*

Coagulant	Formula	Per Cent Fe	Form	Container	Notes
Anhydrous Ferric Chloride	$FeCl_3$	34.4	Powder	150-lb. Steel Drum	Commercial Chemical. Approximately 98% $FeCl_3$
Anhydrous Ferric Sulphate	$Fe_2(SO_4)_3$	27.9	Granular	180-lb Bags 380-lb. Bbls.	Commercial Chemical, over 90% $Fe_2(SO_4)_3$
Crystal Ferric Chloride	$FeCl_36H_2O$	20.6	Lump	435 lb. Bbls.	60% $FeCl_3$
Chlorinated Copperas	$FeSO_47H_2O + Cl$	17.8	Granular Copperas plus Liquid Chlorine	Copperas in 200 lb. Bags 400 lb. Bbls. Bulk Box Cars	88.7 lb. $FeSO_47H_2O$ + 11.3 lb. Cl_2 = 100 lb. Chlorinated Copperas
Liquid Ferric Chloride	$FeCl_3$ + Water	14.5 for average 42% $FeCl_3$ solution	Solution	4,000 and 8,000 gallon Tank Cars	Commercial shipments vary from 39 to 45% $FeCl_3$

Early Processes of Chemical Precipitation in the United States Prior to 1910

Among the processes of chemical precipitation of sewage in vogue in the United States prior to 1910 were those employing the following chemicals as precipitants:

Lime and iron,
Lime and alum,
Lime alone,
Alum alone.

At a few sewage treatment plants, notably those of Worcester, Mass. and Providence, R. I., chemical precipitation processes continued in use for many years after 1910. Chemical precipitation was discontinued at Worcester in 1925 and at Providence in 1934.

Lime and Iron: Powers Process.—Probably the first municipal sewage disposal plant in the United States to utilize a process of chemical precipitation was put in operation at Coney Island, N. Y. during the summer of 1887 (56). Designed by J. J. Powers, the plant consisted essentially of a settling tank, a screen, and a precipitating tank. For several years, perchloride of iron was used as a precipitant, being introduced into the sewage in the precipitation tank. In 1892, the use of lime in addition to the perchloride of iron was begun, the lime being added to the sewage as it entered the first tank. Sludge was burned in a crematory, mixed with the municipal garbage.

Other plants utilizing the Powers process were built at Round Lake, White Plains and Sheepshead Bay, N. Y. (57).

Providence, R. I.—A chemical precipitation plant was put in service at Providence, R. I. in 1901. The plant consisted of 20 tanks: 4 roughing tanks, of which two were about 100 by 101 ft., one 105 by 112 ft., and one about 105 by 123 ft., with an average depth of 11.87 ft. below the outlet weirs; and 16 finishing tanks, each 60 by 115 ft., with an average depth of 8.67 ft. (58). The channels from the roughing tanks were arranged to permit effluent from any of them to be delivered to any finishing tank. The tanks were emptied through floating outlets. The sludge from all the tanks passed to a sludge well 30 ft. in diameter and about 11 ft. deeper than the bottoms of the roughing tanks. The sludge was screened and pumped into sludge reservoirs, from which it was forced into filter presses by compressed air. Pressed sludge cakes were used for filling low land up to July 8, 1908 (59). After that date the pressed sludge was conveyed by a double-bottom scow to dumping grounds at sea.

Providence sewage contained considerable quantities of waste liquor from dye works at certain periods of the day. During the portions of the day when the raw sewage was strongest, copperas was used as a

TABLE IV.—*Data on Operation of Chemical Precipitation Plant at Providence, R. I., 1903–1907 (Using Lime and Copperas)*

Year	Lime Used. (Lb. per m.g.)	Copperas Used. (Lb. per m.g.)	Moisture in Sludge (%)	Estimated Population	Dry Solids in Sludge		Cost per Mil. Gal.		
					Tons Daily	Lbs. per 1,000 Popn. Daily	Chemical Precipitation	Sludge Disposal	Total
1903	606	65.0	94.63	188,500	21.4	228	$3.31	$2.44	$5.75
1904	683	58.0	92.46	193,000	24.9	258	3.42	2.57	5.99
1905	559	51.5	92.11	198,600	22.3	225	3.13	2.66	5.79
1906	638	72.1	92.58	203,000	27.0	266	3.50	3.10	6.60
1907	654	83.1	92.15	208,000	27.3	262	3.54	3.07	6.61

TABLE V.—*Data on Operation of Chemical Precipitation Plant at Providence, R. I., 1903*

Average sewage flow treated—m.g.d.	20.0
Gross capacity of tanks—mil. gal.	11.1
Percentage removal of—	
Total organic matter by albuminoid ammonia	49.80
Suspended organic matter by albuminoid ammonia	82.54 *
Cost of lime per ton	$6.90
Cost of copperas per ton	7.80

* Sewage well screened before treatment.

coagulant in addition to lime, the latter chemical being applied at all times. This procedure was followed until 1908, when the use of copperas was discontinued. The chemicals were added to the raw sewage just above the entrance to a mixing channel, 150 ft. long and 16 ft. wide (60). In this channel were placed slate baffle plates, set 6 ft. apart on alternate sides and lapping each other by 12 inches. After passing through this channel, the sewage entered the roughing tanks.

The effluent from the finishing tanks was discharged into the Providence River off Field's Point at a depth of 36 ft. below mean high water.

Data on the quantities of chemicals used, the character and quantity of sludge produced and the cost of chemical precipitation, given by Metcalf and Eddy (61), are shown in Table IV. Additional operating data for the year 1903, given by Fuller (62), are shown in Table V.

Lime and Alum: East Orange, N. J.—A plant for the chemical treatment of sewage, followed by intermittent soil filtration, was completed in East Orange, N. J., in 1888 (63). The chemicals used were essentially milk of lime and aluminum sulphate, both chemicals being added to the sewage before it entered a square brick main leading to the precipitation tanks. This main was about 100 ft. long. In it the chemicals were mixed with the sewage by means of partitions running part way across, thus forming a "fish ladder." There were two tanks, each divided by low walls into three separate compartments, the total capacity of the tanks being 225,000 gal. (64).

The effluent from the third compartment, after passing upward through a small amount of coke, flowed on to the filtration area, 14.7 acres in extent, all of which was underdrained (65). As the filtration area was restricted in size by local conditions and the soil was of a retentive character, it was supplemented by small artificial beds of coke and gravel. The sludge was drawn from the tanks to a sludge well, from which it was conveyed with the aid of air under pressure to Johnson filter presses and dewatered.

In 1891, the average daily flow of sewage reaching the disposal works was reported as approximately 1.3 mil. gal. (66). At that time not more than 3 grains of lime and 2 grains of sulphate of alumina were being added to each gallon of sewage, although, when the works were placed in operation, Bassett had recommended the use of 8 grains of lime and 10 grains of alum per gallon of sewage. The result was a less efficient precipitation and a greater burden upon the filtration area than originally contemplated.

In 1895, the East Orange sewage treatment plant was abandoned upon completion of an outfall sewer, through which all the sewage of the town flowed to the Passaic River (67).

Lime Alone: Worcester, Mass.—In 1890, a chemical precipitation plant

was put in operation at Worcester, Mass., where great quantities of ferrous sulphate, from the dipping of iron wire into sulphuric acid, were discharged into the sewers (68). Worcester sewage at times was rather strongly acid.

In this plant the sewage was treated with milk of lime, the dosage being controlled to give a slight carbonate alkalinity, as shown by a pink color on adding a few drops of phenolphthalein indicator to the treated sewage. The mixing of the precipitant and sewage took place in a channel provided with baffles projecting alternately from each side, i.e., a "fish ladder," which caused violent agitation of the sewage. The dosed sewage then passed into 6 roughing tanks, measuring about 100 by 66.7 ft. in plan and 7 ft. deep, and afterward into 10 finishing tanks, 166.7 ft. long, 40 ft. wide and 7 ft. deep. Two of these tanks subsequently were used for plain sedimentation as a preliminary treatment for a part of the sewage, which was filtered through intermittent sand filters. The average period of detention in the precipitation tanks was reported as 5 to 10 hr. in 1909 (69).

The sludge drained by gravity to a sludge well, from which it was pumped by a Shone ejector first into sludge lagoons and later into two 20 by 66.7 by 11 ft. covered storage tanks, preparatory to filter-pressing. The sludge was settled in these tanks and the supernatant liquid was filtered on beds of gravel and sand used solely for that purpose and for filtering the press liquor. The sludge was screened upon leaving the storage tanks, from which it was forced by stuff pumps into filter presses, which were installed in 1898. Lime was added to the sludge before it reached the ejector. The sludge cake was dumped on waste land, considerable quantities being taken by the farmers in the vicinity.

The quantity of lime used at Worcester, where the dose of precipitant was changed constantly, in accordance with the needs as shown by phenolphthalein tests, varied widely from day to day and year to year. In 1893, 1,233 lb. per mil. gal. were used as an annual average (70), but as experience was gained in managing the plant and intermittent filters were put into service for treating the strongest sewage by plain sedimentation and filtration, the quantity of lime used was gradually reduced. During 1908, a widespread depression of business resulted in a great reduction of output in the local foundries and wire works and a corresponding reduction in the quantities of acid-iron wastes discharged into the sewer, so that only 871 lb. of lime per mil. gal. were required.

Chemical precipitation at Worcester over a period of 10 years (1903 to 1912) effected an average removal of 42.4 per cent of total organic matter and 82.0 per cent of suspended organic matter, as determined by albuminoid ammonia (71). For these years, the greatest annual average removal of organic suspended matter was 93.1 per cent and the lowest

was 74.7 per cent. However, all the sewage during this time was not treated chemically, but the strongest portions, requiring the most complete treatment, were subjected to plain sedimentation and intermittent filtration, which was started in 1898.

Data on the quantity of solids removed as sludge and the cost of chemical treatment at Worcester, as given by Metcalf and Eddy (72), are shown in Table VI.

The chemical precipitation and intermittent filtration plants at Worcester were superseded by an Imhoff tank-trickling filter plant put in operation in 1925.

TABLE VI.—*Data on Operation of Chemical Precipitation Plant at Worcester, Mass. 1909–1912*

	1909	1910	1911	1912
Quantity of sewage treated chemically (mil. gal. annually)	3,686	3,580	3,610	4,201
Quantity of wet sludge produced (gal. per mil. gal.)	4,210	4,450	4,949	4,551
Moisture in sludge (%)	93.07	91.80	92.48	92.46
Total solids removed (tons annually)	3,642	4,182	4,488	5,065
Total solids removed (tons per mil. gal.)	1.00	1.17	1.24	1.20
Cost per mil. gal.:				
Chemical precipitation	$5.12	$5.25	$5.53	$4.90
Sludge disposal	4.28	4.53	4.60	5.31
Total chemical treatment	$9.40	$9.78	$10.13	$10.21

Providence, R. I.—During the period from 1908 to September, 1934, inclusive (with the exception of 1912, 1913, 1919 and 1920), chemical precipitation with lime alone was practiced at the Providence sewage treatment plant. Pre-chlorination has been a part of the process since 1911, except in 1917. Data on the quantity of lime used, the character and quantity of sludge produced and the cost of chemical precipitation during those years, as given by Metcalf and Eddy, are shown in Table VII. In recent years, approximately 500 lb. of lime have been used per mil. gal. Additional operating data for the year 1910, as given by Fuller (73), are shown in Table VIII. The plant is being remodelled into an activated sludge, to be ready in 1936. Meanwhile, pre-chlorination and sedimentation are being carried on, using drum-type fine screens, two detritors, two primary clarifiers and five final clarifiers built under an earlier contract.

Canton, Ohio.—In 1893, a chemical precipitation plant was completed at Canton, Ohio, the first sewage treatment plant in that state. There were four precipitation tanks, each 50 by 100 ft. in plan, with a depth of

about 5 ft. (74). The total capacity of the four tanks was 700,000 gal., or about one-third of the daily flow in the year 1903. In 1907, the detention period was stated to be 6.7 hr.

TABLE VII.—*Data on Operation of Chemical Precipitation Plant at Providence, R. I., 1908–1910 (Using Lime Alone)*

Year	Lime Used (lb. per m.g.)	Moisture in Sludge (%)	Estimated Population	Dry Solids in Sludge		Cost per Mil. Gal.		
				Tons Daily	Lbs. per 1,000 Pop. Daily	Chemical Precipitation	Sludge Disposal	Total
1908	726	91.77	213,000	24.8	232	$3.42	$3.43	$6.85
1909	700	91.29	217,000	28.5	263	3.36	4.22	7.58
1910	486	92.07	224,300	22.7	202	3.11	4.06	7.17

TABLE VIII.—*Data on Operation of Chemical Precipitation Plant at Providence, R. I., 1910*

Average sewage flow treated—m.g.d.	14.65
Capacity of settling tanks used—mil. gal.	11.13
Percentage removal of—	
Total albuminoid ammonia	48.32
Suspended albuminoid ammonia	82.64

The sewage entered the works through a 4 ft. inlet channel underneath the floor of the boiler room, where, by means of an iron screen having 7/8-inch open spaces, the larger floating matters were taken out and burned under a boiler. Here lime water was introduced into the sewage, which, after flowing about 60 ft., entered the first precipitation tank and from there flowed through the other three tanks, passing over a weir and down a set of aerating steps to an effluent sewer leadng to Nimishillen Creek. When the tanks were cleaned, sludge was allowed to drain into a sludge well, from which it was pumped either to a sludge press (abandoned prior to 1908) or out on the fields. That portion of the sludge which was pumped directly to the fields was plowed under, and the land was planted with corn.

The plant was provided with apparatus for introducing alum into the sewage, but in 1903 it was reported by the State Board of Health that this chemical had not been used for the three previous years, on account of the expense caused by the increase in the amount of sewage. As far as the appearance of the effluent was concerned, the lime alone was reported to be quite as effective. The lime applied ranged from 0 to 16.7 grains per gal., being omitted at times during the winter months. The lime was introduced during 16 hours of the week days, and none at night.

Metcalf and Eddy state that 44 per cent of the suspended matter was removed by chemical precipitation with lime at Canton, equally good results being obtained by plain sedimentation (75). In 1908, the engineers of the State Board of Health recommended discontinuing the use of lime.

Alliance, Ohio.—A chemical precipitation plant was built at Alliance, Ohio, about 1895. Originally planned for use of sulphate of alumina and lime, lime alone was used in 1907 (76). There were three precipitation tanks, each 40 by 80 ft. in plan, with a depth of about 6 ft. The total capacity of the three tanks was about 120,000 gal. or about 1.8 hr. detention period on the average flow for 1907. Lime was applied ranging from 5.6 to 10.7 grains per gal. on monthly averages. The sludge was filter pressed at times. A considerable part of the press cake was taken by farmers, as the soil in certain parts of the surrounding country was somewhat deficient in lime. A test made August 8 and 9, 1906, showed that about 56 per cent of the suspended matter was removed. The general efficiency of the plant was reported as low.

Glenville, Ohio.—At Glenville, Ohio (77) the sewage was treated with lime prior to application to coke strainers and sand filters. The precipitation tanks had a detention period (1907) of 3.7 hr. The area of the sand beds was 1 acre. The plant was badly overloaded (population estimated at 9,000 in 1907) and was abandoned in 1907. The odors from lime sludge pumped onto low land were reported objectionable. About 8.8 grains per gal. of lime were used during 8 hours daily.

Oberlin, Ohio.—The sewage at Oberlin, Ohio (78) was treated with lime and copperas prior to application to a filter and an irrigation area. The plant was greatly overloaded in 1907.

Alum Alone: Columbus Testing Station.—Experiments were conducted at the sewage testing station in Columbus, Ohio, in 1904, on the chemical precipitation of sewage with alum (79), in order to obtain higher rates on the intermittent sand filters receiving the effluent. Screened sewage, settled in a grit chamber, to remove about 30 per cent of the suspended matter was treated with alum before entering a rectangular tank 40 by 8 ft. in plan, with a capacity of 17,600 gal. The average period of flow was 8 hours and the velocity was about 0.42 mm. per sec.

The average dose of alum during the test period, August 16 to November 21, 1904, was 725 lb. per mil. gal. The average removal of suspended matter averaged 74 per cent. The sludge deposited in the tank contained 95.4 per cent moisture and the quantity of wet sludge was 7.77 tons per mil. gal.

Mystic Valley, Massachusetts.—A precipitation plant was in operation in 1888 and for some years thereafter on sewage from Winchester and Woburn containing tannery wastes. Crude sulphate of alumina was used

on a flow of about 324,000 gal. per 24 hr. From 2,400 to 4,000 lb. of alum were used per mil. gal. The precipitation tanks were operated on a fill-and-draw basis with a 3-hour period of quiescence after 3 hours filling (79a).

Miscellaneous: Lawrence Experiment Station.—In 1889, Allen Hazen made a thorough study of chemical precipitation of sewage at the Lawrence Experiment Station (80). Most of his tests were made in 50 gal. barrels, with a settling period of one hour. From 400 to 2,000 lb. of lime per mil. gal. of sewage were used, showing with increasing amounts of lime an improvement in the effluent until all of the free carbon dioxide was neutralized. A larger amount was not effective in removing any more organic matter, but gave increasing removal of bacteria. Copperas and lime were also used, with additions of 500 lb. of copperas and 0 to 2,000 lb. of lime per mil. gal. The results showed that enough lime was needed to combine with the free CO_2 and to precipitate the iron as ferrous hydroxide. The lime was first thoroughly mixed with the sewage and then the copperas added.

In tests with ferric sulphate, from 200 to 400 lb., as ferric oxide, were added per mil. gal., with 400 to 1,000 lb. of lime. Lime was found to be unnecessary if the alkalinity was high enough to decompose the ferric sulphate. The ferric hydroxide was more readily precipitated and more completely insoluble than ferrous hydroxide.

Hazen considered ferric sulphate more satisfactory in general than lime, copperas and lime, or alum. However, he warned that it is impossible to say that one precipitant is universally better than another because of the variations in sewages.

Hazen concludes:

> "It is quite impossible to obtain effluents by chemical precipitation which will compare in organic purity with those obtained by intermittent filtration through sand.
>
> "It is possible to remove from one-half to two-thirds of the organic matter of sewage by precipitation with a proper amount of an iron or aluminum salt."

World's Columbian Exposition, Chicago.—The sewage of the World's Columbian Exposition of 1893 at Chicago was treated by chemical precipitation, using either sulphate of alumina, or copperas, and lime (81). From 900,000 to 2,250,000 gal. per day were handled. The sludge was filter pressed and burned in a garbage crematory.

Degener's Lignite Process

The Degener lignite process has had a limited use in Germany. In this process, dry, powdered lignite was added to sewage and the solids were precipitated by the addition of iron salts (82) or a combination of sulphates of alumina and of iron (83). The process was reported as expensive by Dunbar and also by Schmeitzner. In 1908, there were

about 6 municipal plants in Germany using the Degener process, including Potsdam, Spandau and Tegel. Of these, in 1934, apparently only Potsdam is using the process. The Tegel plant served 14,000 persons, with a sewage flow of about 338,000 gal. per day, about half of which was industrial waste. About 20 lb. of finely ground lignite was added per 1,250 gal. of sewage, and mixed in a "fish ladder" mixer; then sulphate of iron or alumina was added in amount 3 lb. per 1,250 gal. and further mixed. The treated sewage was settled in a vertical settling tank for 1½ to 2 hours. The effluent was removed by a siphon. The sludge was stirred and run to filter presses, which produced a cake of 60 to 65 per cent moisture. The sludge cake was burned at Potsdam in municipal electrical works, or pressed into briquettes and used for fuel. Reichle and Dost (84) state that from 11 to 30 per cent of the calorific value of the sludge came from material of sewage origin.

Electrolytic Treatment

Metcalf and Eddy state:

"A number of proprietary processes have been promoted in which an electrical current is passed through sewage with one or more of the following aims: (1) Production of a chemical precipitant for the removal of suspended solids; (2) neutralization at the electrodes of the electrical charges of colloidal matter and its resultant precipitation; (3) reduction and subsequent oxidation of organic matter by the nascent hydrogen and oxygen produced by electrolysis of the water; (4) deodorizing of the sewage; (5) disinfection of the sewage," (85).

"In the early installations, precipitating chemicals were formed by decomposition of the electrodes, iron hydrate being produced, for example, by the use of iron electrodes. In one of the latter processes, known as the direct oxidation process, lime is added to the electrolyzed sewage. Disinfection and deodorizing are commonly laid to the production of hypochlorites from the salt contained in the sewage, or, when lime is added, to the excess hydrate alkalinity."

"The concensus of opinion of leading engineers seems to be that there are no results of electrolytic treatment of the sewage which cannot be obtained more cheaply and more directly by other more common treatment processes."

Historical: In 1887, Powers took out a patent for generating gaseous chlorine from manganese dioxide, sodium chloride and sulphuric acid for deodorizing and disinfecting sewage. A number of plants were built in the United States under the Powers patent, including installations at Coney Island, Round Lake and White Plains, N. Y., and later, Brooklyn, N. Y. (86).

By 1889, electrolytic processes were being proposed (81). The Webster process (electrical decomposition of iron) was tried at Crossness, one of the London outfalls. A plant was installed at Bradford, England, in 1890, in which it was claimed that 70 per cent of the putrescible matter of the sewage was removed. Webster pointed out the disinfecting value of the hypochlorites formed.

In 1896–1897, Fuller investigated (87) the "Harris magneto-electric process" at Louisville on water treatment and found it did not offer reasonable prospects for practical success (88). A very similar type of apparatus was later installed (86) at Venice and Santa Monica, Cal. (89); Oklahoma City (90, 91) and some six other places in Oklahoma. Some of these were known as the Lautzenheiser process. The practical accomplishments were small. By 1926, all the plants were abandoned, principally because of high cost of operation as compared with the results accomplished.

Landreth (Direct-Oxidation) Process.—The Landreth or so-called Direct-Oxidation Process of electrolytic treatment comprises the use of iron or carbon electrodes between which electric current is passed, and the application of lime to the sewage prior to the electrolysis. The lime is added in excess so as to make a caustic liquid. It is essential that the treatment be followed by a settling basin. The process appears to be primarily one of precipitation due to the amount of lime used, the quantities of lime being larger than was customary in chemical precipitation. From available data, the use of the electrical current effects hardly a measurable improvement over the results obtainable with lime alone, which acts as a coagulant and germicide. Very little oxygen is produced (92) by the electrical current, since from four well known tests the theoretical oxygen produced was about 3 p.p.m., assuming 100 per cent amperage efficiency. This is only one or two per cent of the oxygen demand of typical American raw sewage.

The process was first used in 1914 in a plant built for demonstration purposes at Elmhurst in the Borough of Queens, New York City. In December, 1914, the Bureau of Municipal Research stated (93):

"The bacteriological results can be equalled or bettered by the use of hypochlorite on a previously filtered or settled sewage. The chemical results as shown in the course of experiments are practically identical with and without the use of electric current." "The analyses furnished no proof as to the great increase in oxygen content previously claimed as resulting from the process." "The treatment within the machine can be considered only as a preliminary treatment requiring the period of sedimentation to follow in order to secure any satisfactory degree of purification." Mason, Olson and others, in 1915, when testing a machine with a capacity of 500,000 gal. of sewage per day, practically confirmed these conclusions (94).

In 1915–1916, a test plant was operated at the packing-house of Sulzberger Sons & Co. (now Wilson & Company), in Chicago. The results obtained were said to be unsatisfactory to the packers because the solids from the sewage were so loaded with lime that the material produced was unsaleable.

In 1916, an experimental plant was operated on a large scale at Decatur, Illinois, on sewage containing considerable amounts of corn products waste. Bartow reported (95) that the results obtained with lime alone were better than some of the individual results obtained with lime and electricity. From 2,400 to 3,757 lb. of lime per mil. gal. were used on various runs. The removal of suspended matter with electricity and lime averaged 84.4; with lime alone, 86.4 per cent.

In 1919, an experimental plant was installed at Easton, Pa. The scant data available (96, 97) practically confirm the statement of the New York Bureau of Municipal Research report. Lanphear (98) compares results of the reported test at Easton, Pa. (96) with those at Worcester, Mass., on chemical precipitation with lime. He points out the effect of high caustic alkalinity on stability tests, and states that thirty years experience at Worcester on lime treatment indicate that the direct-oxidation process gives no results of practical value not readily obtained at less expense by using an excess dose of lime.

In 1920, a 3 m.g.d. plant was installed at the City of Phillipsburg, N. J. on extremely weak sewage. The electrolytic procedure has since been abandoned, the plant operating as a plain lime precipitation process since November, 1927.

In 1921, a plant of 3 m.g.d. capacity was installed at Allentown, Pa., consisting of three units. In a test of 31 days in 1922, Johnson reported (99) an average flow of 409,000 gal. The lime used ran from 1,530 to 3,120 lb. per m.g., averaging 2,113 lb. The reduction of 5-day B.O.D. (as calculated from dilution tests) averaged 21 per cent with river water and 40 per cent with distilled water when normally operating. This plant was later tested in 1926 by Metcalf and Eddy (see following) and has since been abandoned.

An extended test was made at Toronto in 1923, by Dallyn, Delaporte and Johnson (100), handling 85 Imp. gal. per min. through the electrolyzer, or about 0.58 of the rated capacity of the machine. An average of 2,764 lb. of CaO per mil. Imp. gal. was used. The conclusion was that the direct oxidation process produced a clarified effluent, and with the requisite causticity a high bacterial reduction, but that chemically the improvement in the raw sewage was not commensurate with that obtained by any of the other established processes.

In tests made by The Sanitary District of Chicago in 1923 with a small apparatus, on sewage received at the Des Plaines River plant, containing an average 5-day B.O.D. of 156 p.p.m., an average reduction in B.O.D. was found after settling, with electricity, of 68.7 per cent; without electricity, of 71.9 per cent. On the sewage received at the 39th Street Pumping Station, containing an average 5-day B.O.D. of 134 p.p.m., an average reduction in B.O.D. was found, after settling, with electricity,

of 63.4 per cent; without electricity, of 65.6 per cent. The dry solids in the sludge ranged from 3,592 to 7,150 lb. per m.g. From 12 to 15 gm. of lime as $Ca(OH)_2$ was added to 50 litres of sewage.

These tests show clearly the effect of caustic alkalinity (101). They also indicate that the electrical current as used was entirely ineffective. The apparatus simply served as a mixer.

Metcalf and Eddy reported (102) on the direct-oxidation plant at Allentown, Pa., which treated the sewage from about 10 per cent of the population. A 7-day working test, summarized in Table IX, shows the effect of treating with the electrolyzer and with the whole process, including preliminary and final settling (theoretically 4.7 hr. at 1 m.g.d.). The final effluent had an average relative stability of 30 per cent.

TABLE IX.—*Results of Test of Direct-Oxidation Process at Allentown*

	Per Cent Reduction	
	Electrolyzer	Complete Treatment
Organic N	No change	19
Albuminoid N	Slight increase	26
Ammonia N	29	33
Nitrite Nitrate N	Slight increase	No change
Oxygen consumed	Slight increase	39
Suspended solids		36
Total solids		67
Chlorides	No change	No change
Alkalinity	Caustic	Caustic
5-day B.O.D.	Increase	35
Bacteria—		
24 hr. 37 deg. C.		Over 99.7
B. Coli per cc	Slight increase	99.4

The bacterial reduction is almost wholly due to the addition of lime, to a high degree of causticity.

The report sums up as follows (103):

"The sewage treatment plant now in operation in Allentown is not of a type suitable for adoption for the treatment of the sewage of the whole city, due to the fact that the purification effected is inadequate, the operating charges are high and the quantity of sludge produced is excessive."

Phelps has aptly summed up the situation as to the degree of effluent produced (104). He states that by taking lime, copperas and bleaching powder in the proportion of 1600, 81 and 125 lb. per mil. gal. respectively, shaking them vigorously for a few minutes, settling for 3 hours, he can produce stability tests apparently showing 100 per cent stability, and bacterial reductions from 1,350,000 in the crude to 25 in the clarified sewage. By such experiments, Phelps found that except for the slight

advantage of the vigorous mechanical action by the paddles in the Landreth apparatus, the results of this electrolytic treatment can be accomplished without the electrolytic feature. Similar studies made by others have shown that the use of liquid chlorine or bleaching powder alone in connection with sedimentation will also produce so-called stable effluents. The cost of such treatment is remarkably less than the combined treatment, including electricity.

In 1935, so far as can be ascertained, only Winston-Salem is using the Direct-Oxidation process. Its plant went into service in December, 1926. According to Thrasher (105), the sewage from a separate system is passed through bar racks, Dorr screens, and a grit chamber. The flow is then brought to a CaO causticity between 50 and 60 p.p.m. by application of a 3 per cent milk of lime solution and then passes to the electrolyzers, in which are iron plates spaced 3/8 inch apart, with current applied at 40 volts and 125 to 150 amp. Pyralin scrapers moving up and down mechanically clean the surface of the plates. Each electrolyzer has 90 plates, each 25 by 16 in. across the tank, and 18 rows lengthwise. The plates require hand cleaning once a month and last about three years. The limed sewage is settled in a Dorr clarifier. The sewage is septic. About 1,500 lb. of lime was used in 1927 on the sewage and 350 lb. for sludge conditioning per mil. gal. of flow. In 1930, 2,019 lb. was used, and in 1933, 1,268 lb. The plant has a rated capacity of 9 m.g.d. The average flow in 1930 was 4.92 m.g.d., and in 1933, 6,416. The population reported is 70,000 connected in 1933. In 1930, 224 KW-hr. were used per m.g., of which 57 went to the electrolyzer. In 1933, total power was 152 KW-hr. per m.g. The results are as follows in per cent removal:

	1927	1930	1933
Suspended Solids	73.5	88	82
B.O.D.—5-day		85	77

The bacterial removal has been high, ranging from 99.5 to 99.9 for 37° tests and 99.9 for B. Coli.

The sludge is reported (105) to have run from 2,445 to 611 lb. per m.g. The moisture content coming from the tank at 92 per cent is reduced on a Feine vacuum filter to 63 per cent. The cost of operation was said to be about $25.88 per m.g. in 1930, exclusive of fixed charges. Somewhat lower costs were reported in 1933.

Acid Treatment

The use of acid in liquid or gaseous form for treating sewage or industrial wastes has been known for many years. The most common applica-

tion was in treating wash waters from wool washing or wool scouring establishments for the recovery of grease. Acid treatment has been used on the largest scale by the City of Bradford, England, one of the centers of wool handling in the world. In other forms, the use of acid in gaseous or liquid form was stimulated during the World War, in the hope of recovery of useful grease. At present, Bradford, Halifax, Morley, and the wool scouring establishments are the only actual users.

Sulphuric Acid.—Bradford for years has been the center of the wool combing industry in England, and therefore has been confronted (106) with the problem of handling a large amount of waste. After various trials of precipitants, in January, 1901, sulphuric acid was used. The main works at Esholt serve a drainage area of 20,156 acres and a population of 273,000 people. The average flow is 29.7 mil. Imp gal. per day, but the hourly flow fluctuates widely because of industrial wastes. Sewage entering the works is one-half domestic and one-half wastes. The yearly average analysis of the sewage handled shows in parts per mil.:

Grease	890
Suspended Matter	1450
Oxygen Absorbed	246
Alkalinity	815

The sewage passes through a grit chamber, and after acidification with sulphuric acid goes through a mixing tank to two series of precipitation tanks, one containing 20 units for the acid cracking process, and the other 20 units for secondary precipitation. The tank effluent is treated on 53 acres of bacterial filters containing ¾ to 1¼-inch coal as filter media. The sludges are screened and then pumped to the sludge disposal building, where the sludge is treated for the extraction of grease and water. About 12,000 to 13,000 tons of acid are used yearly. The acid is made by the City of Bradford at the plant and at its gas works. The sludge is held about 3 months in the tanks, arriving in the filter presses with approximately 80 per cent moisture.

Beedham describes (107) in detail the working of the industrial waste handling at Bradford from individual firms and at the municipal works. Sulphide dyers precipitate the sulphide by copperas.

With Halifax (108) sewage containing large amounts of grease, maintenance of a pH of about 3 and gentle stirring for 7–10 min. increased the amount of solid matter removed in the precipitation tank in 2 hours by 78 p.p.m.

At Morley in Yorkshire (109), grease is recovered by treating the sewage with brown oil of vitriol containing 80 per cent H_2SO_4. The sludge as removed from the tanks contains 30 to 45 per cent grease on a dry basis. At Halifax (108), mixing of non-greasy secondary sludges (activated and trickling filter) with greasy primary sludges proved

TABLE X.—*Acid Treatment of Mixed Packingtown and Domestic Sewage, The Sanitary District of Chicago*

Run in Days	Detention Period Hours	Per Cent Sewage Acidified	Acid Applied 100% p.p.m.	10-Day B.O.D.			Suspended Matter			Ether Soluble		
				p.p.m.		Per Cent Redn.	p.p.m.		Per Cent Redn.	p.p.m.		Per Cent Redn.
				Infl.	Effl.		Infl.	Effl.		Infl.	Effl.	
22	2.2	49.3	444	960	300	69	380	108	71	135	42	69
52	4.0	51.1	403	1,000	260	74	384	110	69	120	40	67
40	2.9	51.1	354	960	520	46	384	102	57	157	92	41
18	2.0	51.9	282	1,120	680	39	354	99	45	138	95	31

impractical. For mixed secondary sludges, lime, ferric chloride and ferric sulphate were the most satisfactory conditioning agents, in order named.

The use of acid in treating domestic sewage mixed with industrial waste was investigated by The Sanitary District of Chicago in 1914–1915 (110). Packingtown sewage was tested. Acid was not applied continuously, being omitted at night from 10 or 11 P. M. to 8 A. M. and entirely on Sunday. Sulphuric acid (66 deg. Bé.) was used, diluted for control purposes. From 282 to 444 p.p.m. were applied on the basis of 100 per cent H_2SO_4. The detention period ranged from 2.0 to 4.0 hours.

The results in removal of various constituents are given in Table X. The amount of acid used applies only to the volume of sewage actually acidified.

Where sufficient acid was applied to provide a considerable excess acidity at all times, a somewhat better removal of suspended matter was obtained than with plain sedimentation. The difference was slight. Scum formation was delayed. The sludge had a foul odor and dried relatively slowly. Because of the high alkalinity of the Packingtown sewage, from 350 to 400 p.p.m. of sulphuric acid appeared to be necessary. At 400 p.p.m., 4,200 lb. per mil. gal. of commercial 60 deg. Bé, acid would be required.

Miles Acid Process.—Miles received a United States Patent, No. 1,134,280, on April 6, 1915, for the use of sulphuric acid or sulphur dioxide for treating sewage (111). Early experiments in the United States were made by E. S. Dorr (112) in June, 1911, at Boston. Weston confirmed his tests (113).

Other tests were made at Baltimore by Requardt (114) by the Massachusetts State Department of Health, and at Gulfport, Miss. The most complete tests were made at New Haven (115) by Mohlman and Winslow, in 1917 and 1918, using about 700 lb. of SO_2 per mil. gal. of sewage. With a 4-hour detention period, 61 per cent of the suspended solids were removed. The effluent was clearer than an Imhoff tank effluent. A deoxidizing influence was noted, which could be obviated by aeration of the effluent, using 0.097 cu. ft. air per gal. of sewage. In this way, 70 per cent of the excess of SO_2 was oxidized in 31 min. A fairly dense sludge (86.6 per cent of water) was produced in New Haven tests as compared with 90.4 per cent from plain sedimentation.

The greatest unknown factor in the cost data for the Miles acid process was the value of the grease. In general, Mohlman indicated a value no more than one-half to two-thirds that of garbage grease, because of the large proportion of unsaponifiable matter.

Tests were made at New Britain, Conn. (116) by the Industrial Wastes Board. About 12,000 gal. per 24 hr. of sewage were treated with a

detention period of 4 hours and an acid dosage ranging from 0 to 2,872 lb. SO_2 gas per mil. gal. of sewage on average runs. The highest daily dosage was 4,450 lb. per mil. gal. The conclusion was that the Miles Acid process was not suitable for conditions at New Britain and that the cost was extremely high.

In a study of the discharge of sewage into Boston Harbor, Goodnough and Clark (117) reported that the Miles Acid process did not seem suitable for the treatment of the sewage of Boston.

Recent Developments in Chemical Treatment

From 1910 to 1928, in the United States, there was very little interest in the development of chemical processes for the treatment of municipal sewage, although the use of chemicals in treating industrial wastes was considered and chemicals were utilized where suitable. However, a more active interest in chemical treatment of municipal sewage appeared around 1929–1930, during which a number of processes were brought forward, of varying degrees of novelty. As the yardsticks of cost and efficiency were applied, the field of usefulness for the various processes has been more clearly defined, although as yet in many cases but little operating and analytical data are available.

Before proceeding to a detailed discussion of the various processes of chemical treatment of sewage which have been more or less prominent since 1910, a very brief summary is presented, as given by Mohlman (101):

Types of Chemicals Used.—"It is difficult to point out new and novel features of chemical coagulants with one or two exceptions. Chemicals used or proposed in recent developments have included the following":

Addition of Coagulants	Addition of Insoluble Solids	Removal of Soluble Solids
Ferric chloride	Paper pulp	Zeolite
Ferric sulphate	Marl	(Ammonia)
Ferrous sulphate	Peat	Chlorine
Lime	Cement dust	
Chlorine	Returned sludge	
Alum	Ground charred sludge	
Sodium Aluminate	Activated carbon	
Copper sulphate	Diatomaceous earth	
	Flue dust	

Recent Chemical Processes.—The recent chemical processes may be classified in 5 groups, according to the type of coagulation:

Ferric Hydroxide plus Zeolite
Guggenheim (Original)
Ferric Hydroxide plus Insoluble Solids
Laughlin
Lewis

Travers
Putnam
Ferric or Aluminum Hydroxide, plus Chlorine
Diamond Alkali
Stevenson
Streander
Cabrera
Scott-Darcey
Calcium Carbonate plus Magnesium Hydroxide
Landreth
Miller-Koller

The important factors, regardless of process, may be summed up under the head of "Developments in Chemical Coagulation":

Developments in Chemical Coagulation.—Among the more recent developments in chemical coagulation may be listed (118, 119) the following:

1. The adjustment of the hydrogen ion concentration for optimum coagulation.
2. The development of devices for controlling the pH.
3. The introduction of stirring by air or mechanical means to promote floc formation prior to sedimentation.
4. Improved equipment of various types, including:
   (*a*) Tank equipment.
   (*b*) Chemical feed—
      1. Dry.
      2. Mechanical control.
5. The decrease in the cost of the ferric salts which are the more efficient, such as ferric chloride or ferric sulphate.
6. The availability of liquid chlorine at greatly decreased cost.
7. The general reduction in the cost of chemicals.
8. Improved facilities for shipping and handling corrosive iron salts.
9. The availability of improved vacuum filters for dewatering sludge.

Among other and older ideas which have been revived of late are:

1. The introduction of inert material to weight the sludge.
2. The return of the precipitated sludge to the raw sewage.
3. The use of air for mixing.
4. The splitting of the procedure into two stages, utilizing a preliminary settling followed by coagulation and precipitation.

The Laughlin Process

The Laughlin Process of chemical treatment of sewage derives its name from W. C. Laughlin, whose magnetite filter has been associated with the process throughout its entire development. During the first stage of development of the Laughlin Process, emphasis was placed on the scheme of coagulation, in which the coagulants used were ferric chloride, spent wet lime sludge from calcium carbide used in the manufacture of acetylene, and macerated paper pulp. Ferric chloride was at first manufactured from waste iron scrap and chlorine in an absorption tower, but difficulties in the operation of this process have led to its abandonment and to the use of a purchased solution of ferric chloride. Ferric sulphate has also been used for short periods. Paper pulp at first was considered a waste product, free of cost except for the hauling, but later experience has indicated that the cost may be quite substantial if waste paper must be purchased, consequently the use of paper pulp has waned. Spent lime from acetylene manufacture is not always available, and commercial lime must then be purchased.

The more recent developments sponsored by Laughlin have tended to divert attention away from the original emphasis on the use of manufactured chemicals, by-products, etc., and have focussed attention on the use of the Laughlin Magnetite Filter for all conceivable phases of sewage treatment in which additional clarification might be desirable above that attainable with settling tanks. The history of the Laughlin Process has therefore shown changes in trend or policy similar to those noted in the history of the Guggenheim Process. (See page 1041.) These changes are, however, characteristic of the development of all types of sewage treatment. The Laughlin Process has received more publicity than any other chemical process during the recent revival of interest in chemical treatment and has been installed at Dearborn and Perth Amboy. The earliest interest centered on the plant at Dearborn, Mich., built in 1931–32, following the operation of a testing station in 1930–31.

Dearborn Experimental Plant.—The experimental plant included a wooden settling tank 30 ft. by 12 ft. in plan and 12 ft. deep, providing 1½ hours detention for a flow of 0.5 m.g.d. About 600 lb. of lime, 200 lb. of ferric chloride and 300 lb. of paper pulp were added to the incoming raw sewage prior to sedimentation. The effluent from the settling tank passed upward through trays containing crushed magnetite, which filtered out the suspended solids or floc. The filtered effluent was chlorinated.

Average results of operation over a period of ten weeks were as follows:

	Raw	Parts per Million			
		Effluent		Per Cent Reduction	
		Settled	Chlorinated	Settled	Overall
Suspended Solids	175	26			86
5-day B.O.D.	100	55	33	45	67
Ammonia N	15	14			
Organic N	2.9	1.5			

Dearborn Plant.—Upon the completion of the experimental work, a full-size Laughlin plant was built at the West Side (120) to handle a limited amount of sewage from the West Side, plus sludge pumped from the East Side Imhoff-tank plant. The West Side plant includes two 60 ft. diameter tanks, one of which has been used most of the time for East Side sludge, and the other for West Side sewage, providing a 1-hour period of sedimentation for 4 m.g.d. The Laughlin magnetite filters are constructed around the inside wall of the clarifiers at the top. The bottom of the filter is a slotted screen of phosphor bronze, 8 ft. wide, with openings 1 millimeter in width. A 3-inch layer of magnetite (10 to 20 mesh) rests on this screen, through which the settled effluent flows upward. The magnetite is cleaned continuously by a traveling peripheral electro-magnet, which is intermittently electrically energized, thus lifting the magnetite and permitting a rush of water through the bed. The wash water is removed by a pump mounted on the traveling device, and is re-treated. The filtered effluent is chlorinated. Sludge was filtered on Oliver filters and dumped on local or city property until 1935, when a Nichols-Herreshoff furnace was put into operation and the combustible matter in the filter cake incinerated.

Many published articles have described the Dearborn plant and presented data on its operation (121, 122). The treatment of sludge from the East Side plant has introduced conditions different from those presented by the usual sewage treatment works. Likewise, until recent months the flow of West Side sewage has been much below the designed capacity, as the sewerage system has not been extended as contemplated. However, data on the treatment of sewage alone have been reported when available. The significant data on the treatment of sewage only, and not sewage with sludge, are as follows:

1. Sewage only, treated June 13–30, 1932.
2. Report by S. I. Zack (123).
3. Test run by A. M. Buswell (124).

4. Report on two years' operation by M. B. Owen (125).
5. Recent data (May, 1935).

The operating data and results obtained during these periods are shown in Table XI.

TABLE XI.—*Laughlin Process at Dearborn. Operating and Analytical Data*

Period of Test	M.G.D. Treated	Chemicals, Lb. per M.G.		
		$FeCl_3$	Lime CaO	Paper
1. June 13–30, 1932	0.96	260	352	313
2. *Zack*—May 21–July 19, 1932	1.11	235	245	285
3. *Buswell*—Oct. 30–Nov. 28, 1933	2.40	251	220	360
4. *Owen*—Nov. 1933–April, 1934	1.74	306	147	73
5. May, 1935	3.87	256	152	0

Period (as Above)	Suspended Solids			5-Day B.O.D.			Remarks
	Raw	Effluent	Per Cent Red	Raw	Effluent	Per Cent Red	
	Parts per Mil.			Parts per Mil.			
1	181	18	90	108	45	59	Eff. Chlorinated
2	212	20	91	112	38	66	" "
3	227	18	92	113	28	75.2	Eff. not Chlorinated
4	230	19	92	128	28	78	" " "
5	101	25	76	95	37	62	" " "

These results indicate a range of chemicals for coagulation as follows:

Ferric Chloride	235 to 306 lb. per m.g.
Lime	147 to 352 lb. per m.g.
Paper	0 to 360 lb. per m.g.

There appears to be a tendency to reduce the amount of chemicals used since operation began in 1932. The use of paper is reported to have ceased. The effluents in all tests were comparatively constant, in parts per million, although the percentage reductions showed wide variations.

Sludge Disposal at Dearborn.—The Oliver filters at Dearborn have produced an excellent cake, containing from 60 to 75 per cent moisture. This cake was dumped until 1935, but is now incinerated. A 90-day acceptance test of the Nichols-Herreshoff furance was completed in June, 1935 (126).

Cost.—The Dearborn Plant, as reported by Owen, cost $501,702.

The cost per million gallons cannot be estimated satisfactorily because of the inclusion of sludge treatment for the East Side Plant. Likewise, it is difficult to break down the operating costs per million gallons of sewage treated.

Tests at Coney Island.—In August and September, 1931, an 11-day test of the Laughlin Process was made by Zack and Hurwitz (127) in a small experimental plant at Coney Island, N. Y. In these tests the chemicals used per million gallons were:

Lime—900 lb.;
Ferric chloride—161 lb.;
Paper—385 lb.

The analytical results were:

Suspended Solids:
Raw Sewage—132 p.p.m.
Final Effluent—10 p.p.m.
Reduction—92 per cent.

5-Day B.O.D.:
Raw Sewage—132 p.p.m.
Settled Effluent—41 p.p.m.
Final Effluent—28 p.p.m.,

showing a reduction in B.O.D. of 69 per cent in the settled sample and 79 per cent with chlorine.

In 1934–35, this Coney Island testing station was again operated. The results have been reported by Rudolfs, Brendlen and Carpenter (128) (See page 1059, Mechanical Filtration of Sewage Effluents).

Perth Amboy.—A Laughlin plant was built in Perth Amboy, N. J. and placed in operation July 1, 1935. This plant consists (119) of bar screens, flocculating chambers and air mixing, two circular settling tanks, each 80 ft. in diameter (each with a 1-hour detention period at flows of 10 m.g.d.), equipped with Laughlin magnetite filters. Ferric chloride and lime are used for flocculation, but no paper. The effluent is chlorinated. The use of chemicals is to be seasonal, no chemicals being used during 8 or 9 months of the year. The sludge is filtered on vacuum filters installed by the Filtration Equipment Corporation. The sludge cake is hauled away and dumped. The effluent is discharged into Raritan Bay. The Perth Amboy plant is designed to treat average flows of 10 m.g.d. and a maximum of 20 m.g.d. The construction cost is reported to be $375,000.

The sewage flow in July, 1935, averaged 2.56 m.g.d. The suspended solids were reduced from 214 to 21 p.p.m. when using 290 lb. of ferric chloride and 650 lb. of lime per mil. gal. In August, the suspended

solids were reduced from 264 to 34 p.p.m., when using 214 lb. of ferric chloride and 680 lb. of lime per mil. gal. In September, no chemicals were used.

The Guggenheim Process

A large amount of experimental work has been conducted by the research department of Guggenheim Brothers in an effort to develop a complete chemical and mechanical process for the treatment of sewage and the disposal of sludge (129). The distinctive feature of this process, as first developed, was the use of a zeolite filter following chemical flocculation and sedimentation. In the more recent Guggenheim experimentation, however, the zeolite filter is not used, but instead the chemically flocculated sewage is aerated for approximately one hour, followed by sedimentation and continuous return of a portion of the settled sludge, thus constituting a procedure similar to the activated sludge process.

Throughout the Guggenheim experimentation there was the desire to develop a process surpassing chemical flocculation in degree of purification. This goal was attained by the use of zeolite, and also to some extent by the more recent procedure, but the improvement in the quality of effluent has increased the cost of the process over the cost of plain chemical precipitation.

The Guggenheim investigations have comprised:

1. Small-scale operation (2,400 gallons per day) for one year at the laboratory of Guggenheim Brothers in New York City, using sewage from Dyckman St. during 1931 and 1932 (130).
2. Operation of a 28,000 g.p.d. experiment station at the North Side Sewage Treatment Works of The Sanitary District of Chicago, from March, 1933 through September, 1933 (131).
3. Experimental work at Raleigh, N. C. during 1934, without zeolite filter.
4. Small scale experiments at Dyckman Street screening plant, New York City, in the winter of 1934–35, without the zeolite filter, but with aeration of chemically treated sewage, and return of settled sludge.
5. Larger scale experiments (80,000 g.p.d.) during the summer of 1935 at New Britain, Conn., using the procedure developed at Dyckman Street, with no zeolite.

The Guggenheim investigations have been a valuable contribution to the knowledge of chemical treatment of sewage, indicating that the zeolite filter was effective in removing ammonia and amine nitrogen, and that the effluents obtained during the work at the Chicago North Side Plant were equal in quality to an activated sludge effluent. However, the estimated cost of the Guggenheim Process, using zeolite, has been too high to permit competition with the activated sludge process

(132). As yet there are insufficient data to permit accurate cost estimates of the newer chemical aeration process. So far all of the installations of Guggenheim Brothers have been experimental.

Procedure.—The Guggenheim Process, as first developed, comprised the following steps:

1. Removal of suspended solids by coagulation with ferric compounds and lime, and settling the coagulated solids in the form of a sludge.
2. Disposal of the sludge by filtration and incineration. (Regeneration of the iron as ferric sulphate from the incinerated ash.)
3. Removal of soluble nitrogenous compounds (and possibly carbonaceous) by filtration through a bed of zeolite.
4. Regeneration of the zeolite by means of salt solution, distillation and recovery of ammonia from the spent salt solution, and discharge of the salt-containing residual liquor.

The process thus was complete, but complex as compared with current types of sewage treatment.

Results Obtained.—The more significant results obtained during the experiments at Chicago (Table XII) indicate that most of the work was done in the settling tank preceding the zeolite filter, by chemical precipitation, using large amounts of ferric sulphate. Although the zeolite filter improved the effluent and removed all but traces of suspended solids, the reduction of B.O.D. by the filter was comparatively small and was obtained at the expense of a large amount of salt required for regeneration of the zeolite.

TABLE XII.—*Guggenheim Process, North Side Sewage Treatment Works, Sanitary District of Chicago. Analytical Data*

Month 1933	5-day B.O.D.					Suspended Solids				
	Parts per Million			Per Ct. Reduction		Parts per Million			Per Ct. Reduction	
	Raw	Coag. & Settled	Final	Coag. & Settled	Overall	Raw	Coag. & Settled	Final	Coag. & Settled	Overall
March	98.5	23.4	11.5	76.2	88.3	135	20	1.8	85.3	98.7
April	100.6	20.3	11.7	80.2	88.4	127	17	1.5	86.7	99.0
May	77.4	12.7	8.0	83.6	89.7	120	15	1.5	87.4	98.8
June	112.0	16.5	10.4	85.2	90.7	146	25	3.6	82.8	97.5
July	94.0	16.0	8.3	83.0	91.2	119	33	4.8	71.6	96.0
August	113.8	16.1	8.2	85.8	92.8	135	24	5.3	82.2	96.1
Sept.	123.0	18.7	6.1	84.8	95.0	151	25	5.2	83.4	96.6

Month 1933	Analytical Data					Chemicals for Coagulation			
	Ammonia Nitrogen (N)					Parts per Million		Lb. per Million Gallons	
	Parts per Million			Per Ct. Reduction		Ferric Sulphate as Fe	Lime as CaO	Ferric Sulphate	Lime
	Raw	Coag. & Settled	Final	Coag. & Settled	Overall				
March	6.9	7.5	2.0	Inc.	65	32.1	43.1	960	358
April	6.6	6.8	2.3	Inc.	65	31.3	45.8	930	380
May	5.5	5.2	1.6	5	71	38.5	52.4	1140	435
June	7.9	7.6	3.2	4	60	27.0	49.4	805	411
July	7.7	7.4	3.2	4	58	24.5	46.7	730	388
August	8.6	8.3	2.8	3	67	26.2	52.9	778	440
Sept.	8.5	8.2	3.2	3	63	19.5	31.6	570	262

The Guggenheim scheme included incineration of the sludge and leaching of the ash with sulphuric acid for regeneration of ferric sulphate. The purchase of sulphuric acid instead of ferric sulphate would effect a considerable saving, according to the Guggenheim cost estimates. For purposes of cost estimates, the Chicago data indicated the use of the following chemicals.

	Lb. per Million Gallons
Sulphuric acid, 66° Bé	960
(Equivalent to ferric sulphate	800)
Lime (as CaO) for coagulation	410
Lime (as CaO) for sludge filtration	40
Lime (as CaO) for liberating ammonia from brine	230
Salt (as NaCl) for regenerating zeolite	840

The cost of chemicals at Chicago was estimated as follows by the Guggenheim staff:

	Lb. per Million Gallons	Cost per Ton	Cost per M.G.
66° Bé Sulphuric Acid	960	$9.00	$4.32
Ground Lime	680	7.00	2.38
Salt	840	5.75	2.42
			$9.12

Similar estimates made by the D'Esposito-Kutz-Mead-Storey PWA Commission for The Sanitary District of Chicago indicated (126) the following quantities and costs of chemicals:

	Lb. per Million Gallons	Cost per Ton	Cost per M.G.
66° Bé Sulphuric Acid	740	$12.00	$4.44
Ground Lime	730	9.00	3.29
Salt	840	6.10	2.63
			$10.36

The recovery of ferric sulphate from the ash by treatment with sulphuric acid appeared essential to minimize the cost of the iron coagulant. In the experimental work, most of the iron salts added were purchased as ferric sulphate, although for short periods, regenerated ferric sulphate was produced. The amount of acid required for regeneration of ferric sulphate will vary with the alkalinity and hardness of the sewage.

Considerable study was given during the earlier Guggenheim work to the possibilities of ammonia recovery and sale. In the first work at Dyckman Street, it was estimated that 100 lb. of ammonia (NH_3) per million gallons would be recovered. At Chicago, only 40 lb. per m.g. was recovered. It was claimed that this ammonia could be sold for 4½ to 5 cents per lb.

Recent Developments.—The zeolite filter, while of considerable interest as a final treatment for chemically clarified sewage, has not been considered with favor for full scale installation because of the cost and the lack of experience as to its use on a large scale. At Raleigh, N. C., where a completely treated effluent was apparently unnecessary, Guggenheim Brothers proposed to install only chemical flocculation and sedimentation. A plant of this type was designed for Raleigh, but has not been built. More recently, the Guggenheim work at Dyckman Street and New Britain has comprised a combination of aeration, plus chemicals, with the return of sludge. The data on these investigations have not been published.

The Streander Process

Experiments on the Streander process of sewage treatment were conducted in 1932 at the Northeast Sewage Works in Philadelphia, Penn., in a plant designed to treat about 25,000 gal. per day of screened sewage (133). Ferrous sulphate (240 lb. per mil. gal.) and lime (480 lb. per mil. gal.) were added to the raw sewage and air (0.06 cu. ft. per gal.)

blown through the mixture, thus converting the ferrous sulphate into ferric hydroxide. The coagulated sewage then flowed to a combination radial-flow settling tank and filter with a detention period of 1½ to 2 hr. The effluent passed through a submerged filter, consisting of a layer of sand or anthracite coal resting on a screen, at a rate of filtration varying from 1½ to 2½ gal. per min. per sq. ft. of filter area. The precipitated sludge was removed mechanically from the bottom of the tank. Blew reported a reduction of 5-day B.O.D. between 75 and 80 per cent and of suspended solids from 92 to 95 per cent.

The Cabrera Process

Experiments on a small scale were conducted in 1931 at the sewage works of Wilmington, Del., on the chemical precipitation of sewage by a process devised by R. J. Cabrera. In the experiments, the screened sewage flowed through a mixing tank, 8 by 3 ft. in plan, provided with 12 baffles, spaced 6 in. apart. The best results were obtained when using 3 grains per gal. (428 lb. per mil. gal.) of filter alum. A portion of the precipitated sludge, removed from the sedimentation tank, containing from 1 to 1.5 per cent solids, was added at the third baffle of the mixing tank. The best results were obtained when the amount pumped back equalled 15 per cent of the volume of the sewage. The flocculated sewage flowed into a settling tank, 24 by 5 by 3.5 ft., with a detention period varying from 1/2 to 2 hr. The average results obtained over a period of six months indicated a reduction of 5-day B.O.D. from 147 to 32 p.p.m. and of suspended solids from 194 to 21 p.p.m.

Several methods for treating the sludge were tried. When dewatered on sand beds, the sludge dried slowly and gave off considerable odor. Vacuum filters reduced the sludge moisture to 85 per cent, but the cake produced objectionable odors. Another test showed that the sludge digested in a normal period of time with a gas production equivalent to that from non-precipitated solids. The digested sludge was dewatered on a vacuum filter with a cake containing from 76 to 80 per cent moisture.

No larger development of these small-scale experiments has been reported.

The Stevenson Process

The Stevenson Process resulted from studies made in 1931 under the direction of R. A. Stevenson, then Research Engineer for the Great Western Electro-Chemical Company, at an experimental plant erected and operated at Palo Alto, California, through the cooperation of the City of Palo Alto, Leland Stanford University, and the Great Western Electro-Chemical Company. The process consists of coagulation with ferric chloride and sedimentation, in two or more stages. The re-use of spent coagulant either by regenerating the sludge with chlorine or by

the return of the final sludge to the raw sewage is an essential part of the process. The Great Western Electro-Chemical Company is said to own U. S. Patent No. 1,946,818, which claims the regeneration of coagulants with chlorine.

The process is described in five articles (134, 135, 136, 137, 138), one of which (137) contains considerable analytical data for a test period of 28 days.

The experimental plant at Palo Alto is described by Stevenson (130) as follows:

1. Primary Clarifier.
   Retention period 2 hr. 30 min.
   Settling rate 345 gal. per sq. ft. per day.
2. Two mixing tanks in series (time not given).
3. Secondary Clarifier.
   Retention period 1 hr. 30 min.
   Settling rate 504 gal. per sq. ft. per day.
4. Two mixing tanks in series (time not given).
5. Final Clarifier.
   Retention period 3 hrs.
   Settling rate 260 gal. per sq. ft. per day.

The tests were run on sewage from the City of Palo Alto, which was passed through a bar screen with ½-inch openings and pumped into the experimental plant at a constant rate of 25 gal. per min. throughout the 24 hours.

Tests on the complete process, with regeneration of spent sludge, were made (134) but detailed analytical results have not been published. The sewage used in the tests averaged 255 p.p.m. 5-day B.O.D. and 250 p.p.m. suspended solids. It is claimed that an overall reduction of B.O.D. of 95 per cent was accomplished with the use of one grain of ferric chloride per gal. (143 lb. per mil. gal.). The chemical cost of this treatment was estimated at $15.00 per mil. gal.

Following the tests on the complete process, a run of 28 days was made with two of the clarifiers and one set of mixing tanks in service, the regeneration of spent sludge with chlorine not being used. The strength of the sewage and the character of the effluent were as follows:

	5-Day B.O.D. p.p.m.	Suspended Solids p.p.m.
Raw Sewage—		
Average	306	290
Maximum	373	480
Minimum	223	160
Effluent—		
Average	106	42.6
Maximum	150	120
Minimum	20	20

The average reductions in per cent were 65.5 of B.O.D. and 85.3 of suspended solids.

The chemical cost was estimated by Stevenson (131) per mil. gal.:

Sterilization of effluent; chlorine—83.3 lbs. at $.03	$2.50
Coagulation; 142.8 lbs. ferric chloride at $.03	4.28
Sludge conditioning;	
18 lbs. ferric chloride at $.03	.54
180 lbs. lime at $.006	1.08
Total	$8.40

In this test, sludge amounting to 1,800 lb. of dry solids per million gallons was removed, conditioned with ferric chloride and lime and dewatered on an Oliver filter, but it is stated (136) that the sludge from the process may be digested.

In general, this method presents an interesting study of sewage treatment by coagulation, particularly as regards economical use of coagulant. The adaptation of old principles of mixing and flocculation, as well as the circulation of sludge, are of interest. The published data on the regeneration of spent sludge are too meagre to warrant discussion.

Shades Valley Plant

Hendon has conducted a series of tests in the Shades Valley plant at Birmingham, Ala., utilizing chlorinated copperas (139, 140, 141). The plant serves about 3,500 population with a flow of 1 m.g.d. but is designed for 15,000 population and 2 m.g.d. The plant includes bar screens with ¾ in. clear openings; a 5 by 5 ft. flash mixer with variable speed impeller; a 22 by 21 by 7½ ft. flocculator, divided into 2 units, equipped with 3 rows of paddles, with a period of 30 min. at a flow of 2 m.g.d.: 2 clarifiers, each 45 ft. diam. by 7 ft. side water depth, each providing 1 hr. detention period on a 2 m.g.d. flow; a 2-stage digestion system and miscellaneous equipment. The plant is designed for extremely flexible operation by at least five methods, as follows:

A. Plain parallel sedimentation with one-half the sewage flowing through each settling tank, with or without flocculation.

B. Plain series sedimentation with the sewage flowing through the primary clarifier and thence through the flocculator and secondary clarifier.

C. Parallel operation with chemical precipitation of the screened sewage with the sewage flowing through the flash mixer, flocculator, and thereafter one-half to each clarifier, either with or without the return of sludge to the crude sewage.

D. Series operation of clarifiers, with chemical precipitation applied to the settled sewage. The sewage flows through the primary clarifier, flash mixer, flocculator and secondary clarifier; with or without the return of sludge to the crude sewage. Hendon considers this the most effective method for normal operation with chemicals.

E. Screened sewage flows first through one-half of the flocculator, mixing with all of the chemical sludge from the secondary clarifier. This mixture flows to the primary clarifier. The settled sewage passes to the rapid-mixer, where the coagulant and chlorine are added, and then flows through the other half of the flocculator into the secondary clarifier.

Chlorine can be added, as desired, ahead of each clarification stage and also to the raw sewage before it enters the screen chamber.

Hendon believes (141) that Method *D* has the following advantages:

1. Odors are prevented by return of chemical sludge to the raw sewage;
2. The amount of chemicals is reduced by pre-sedimentation;
3. The return of sludge makes more uniform sludge for digesters;
4. The chemical sludge concentrates more readily when re-settled with raw solids;
5. Any excess of chemicals added is utilized by return of sludge;
6. The preliminary settling tends to smooth out hourly variations in suspended solids;
7. The return of the chemical sludge to the raw sewage raises its pH value from 6.6 to 6.9 (mixed sludge).

Chemicals are added on a seasonal basis, none being used in the winter. Results available for about 60 days prior to December 1, 1934, indicate a weak sewage, with average analyses as follows:

Determination	Raw Sewage p.p.m.	Effluent p.p.m.
5-Day B.O.D.	80	10
Suspended Solids	100	9
pH	7.1	
Alkalinity	130	
Iron Content	2	

The results noted were accomplished with about 70 lb. of chlorine and 440 lb. of ferrous sulphate per mil. gal. The cost of chemicals averaged $5.40 per mil. gal. of sewage treated, based on ferrous sulphate delivered at $17.50 per ton and chlorine at 3 cents per lb.

The estimated cost of operation (2 m.g.d.) including fixed charges at 7½ per cent (on $108,000) was $23.65 per mil. gal. On a 12 m.g.d.

basis at Ensley, this cost was estimated at $13.84 per mil. gal. In the estimates the labor costs given are at low rates, and relief men are omitted.

The published data are valuable, but are not sufficiently complete to warrant the conclusions that preliminary sedimentation is of advantage, either in reducing chemical costs or producing a more easily digested sludge, or that preliminary sedimentation with return sludge produces a more uniform sewage at point of chemical application, or that such a process is more economical than the activated sludge process or better adapted to meet daily and seasonal variations than are biological processes.

The Scott-Darcey Process

The Scott-Darcey process is primarily not a process of sewage treatment but rather a method of manufacture, regulation and application of coagulating chemicals made from chlorine and scrap iron. Either ferrous or ferric chloride may be made at the plant site by this process and these chemicals are as applicable to coagulation of water as they are to that of sewage. This process was developed at the sewage treatment works of Oklahoma City, Okla. by L. H. Scott and H. J. Darcey. Patents are said to have been applied for.

The process consists essentially of preparing a chlorine solution of regulated strength and allowing it to pass through a column of scrap iron. Control of the concentration of the chlorine solution, as well as the time of contact, is essential, since these features determine the character of the coagulant. Experiments indicate that ferric chloride will be formed when the solution contains from 28 to 40 gal. of water per pound of chlorine and that ferrous chloride will be formed when this chlorine concentration is materially decreased or when a long period of contact with the scrap iron is permitted. Commercial liquid chlorine is used and in most of the existing installations this is applied through a chlorinator of the vacuum type equipped with a small meter on the water inlet. Scrap iron such as lathe turnings and tin cans has been used successfully but the former seems to be the most satisfactory, due probably to the large amount of surface exposed to the action of the solution (142).

Practically no difference is reported between the action of the chemical manufactured by this process and the various commercial forms when dosages are compared on the basis of net amounts. Therefore, the advisability of its use depends largely upon its relative cost as compared with that of the commercial produce.

Roughly, 70 lb. of chlorine and 30 lb. of iron are required to make 100 lb. of ferric chloride. Similarly, 55 lb. of chlorine and 45 lb. of iron are required to make 100 lb. of ferrous chloride. In most of the installations,

the coagulant is produced in concentrations of 0.25 per cent or lower, but in some of them, notably the one at Oklahoma City, this concentration is increased by re-circulation and additional chlorination to 3 per cent or higher.

The cost of coagulant made by this process varies with the cost of chlorine, which is influenced largely by the amount used. If one or two cars (30,000 lb. to 60,000 lb.) per month are used, chlorine is obtainable in single unit tank cars at approximately 2 cents per lb. f.o.b. factory. If a similar amount is used yearly, it is obtainable in multi-unit cars at a slight increase in its cost per pound. If the consumption of chlorine falls much below 100 lb. daily, it must be purchased in small cylinders at prices which range from 8 to 11 cents per pound.

The cost of materials for making the coagulant at various chlorine prices, with an allowance of $10.00 per ton for scrap iron, and disregarding the cost of solution water, is as follows:

With chlorine in tank cars at $2.85 per cwt.:	
70 lbs. chlorine	$1.995
30 lbs. iron	.150
100 lbs. ferric chloride	$2.145
With chlorine in multi-unit cars at $3.00 per cwt.:	
70 lbs. chlorine	$2.10
30 lbs. iron	.15
100 lbs. ferric chloride	$2.25
With chlorine in small cylinders at $10.00 per cwt.:	
70 lbs. chlorine	$7.00
30 lbs. iron	.15
100 lbs. ferric chloride	$7.15

Since the economy of the process depends largely on the cost of chemicals, the location of the project in relation to the sources of the chemicals is important. At Denver, Colo. for instance, anhydrous ferric chloride is quoted at $75.00 per ton, while it is estimated that ferric chloride can be made by this process at approximately $40.00 per ton, or about the factory f.o.b. price of the commercial form. Generally speaking, this process appears limited economically to projects which warrant the use of chlorine in multi-unit or single unit cars.

Scott describes (143) the treatment given in a 5 m.g.d. plant at Oklahoma City to a strong, septic sewage, high in H_2S. The sewage passes through a $\frac{3}{8}$-inch opening screen, and is treated with lime to a pH value of 8.5. Ferric chloride is then added (6 p.p.m.) and mixed for 20 minutes in a flocculator, then settled in two primary clarifiers. The

effluent is chlorinated (8 p.p.m.) and allowed to settle. The settled sludge is continuously removed from both primary and secondary clarifiers and pumped to the vacuum filter for dewatering. Existing Imhoff tanks were converted into digesters. Suspended solids have been reduced from 200 to 10 p.p.m. The 5-day B.O.D. has been reduced from 185 to 19 p.p.m. On the average Scott states that 753 lb. of lime were used per day and 51 lb. of $FeCl_3$. A total of 2,500 lb. per mil. gal. of dry solids was recovered as sludge, with a filter rate of 5.5. lb per sq. ft. per hr.

At Princeton, N. J., Riker reports (144) that chlorinated iron (made from tin can scrap treated with chlorine in aqueous solution) applied to raw sewage—

> Improved performance of primary settling tank.
> Improved sludge digestion, with a clearer supernatant.
> Improved odor control.
> Resulted in economy of chlorine.
> Improved operation of trickling filters.
> Improved sludge drying.

The treatment was primarily used to control H_2S odors from stale sewage with a B.O.D. of 225 p.p.m. The summer chlorine demand was 25 p.p.m. A total of 20 p.p.m. of chlorine was required at times.

The Scott-Darcey process is used at York, Nebraska. The scheme of treatment includes two stages, with intermediate mixing and flocculation, the sludge from the final tank being returned to the primary tank for re-settlement. Results of 24-hour composites for 7 days, using from 100 to 198 p.p.m. of chlorine and 88 to 269 lb. of lime per mil. gal., show reductions in suspended matter ranging from 69 to 88 per cent, and reductions in 5-day B.O.D. (on 4 days) ranging from 59 to 75 per cent. The plant treated from 186,900 to 265,000 gal. per day. Some tests with an experimental rapid sand filter (6 inches of sand (0.45 mm.) on 12 inches of graded gravel) have shown as improvement in removal of suspended matter, giving an overall reduction of from 91.6 to 97.8 per cent.

The plants utilizing the Scott-Darcey process are listed in Tables XXI, XXII and XXIII.

Ferric Chloride Generators.—Steel and Zeller point out (145) the difficulty of operating a ferric chloride generator on a small scale, with the use of scrap iron and chlorine gas. Transite pipe proved best able to resist corrosion. Trimble indicates (146) that chlorine water is a better solvent for iron than hydrochloric acid. Loose packing of iron turnings prevents plugged lines. The rate of feed of chlorine water through the iron is important, as a low rate results in ferrous chloride.

The color of the solution is reported redder than for ferric chloride solutions of equal strength.

Lewis-Travers Process

Various combinations of chemicals and inert substances for treatment of sewage have been proposed under the name of the Travers-Lewis process. Recently two distinct lines of operation appear to have been followed, known separately as the Travers and the Lewis processes. A number of United States patents issued to Travers are listed in Appendix A.

Travers (Marl) Process.—In 1924, Ashland, Ohio, installed equipment at its sewage treatment works for the treatment of the sewage by the Travers marl process. The original plant consisted of septic tanks and sand filters. The precipitant used was a mixture of finely divided marl, hydrated lime and granulated ferrous sulphate, in the proportions of 81.2, 16.2 and 2.6 per cent respectively, 2,772 lb. being added to 350,000 gal. of sewage. Later the proportions used were 87, 12.5 and 0.5. More recent tests (101) over a period of 12 days, with an average flow of 500,000 gal. per day, gave approximately 85 per cent reduction of suspended solids and 50 per cent reduction of B.O.D. At various times different combinations have been used, such as lime, ferrous sulphate, ferric chloride and an electrolyte. Recently marl, lime and ferrous sulphate have been used, fed in the dry state.

Allen and Dakin have recently conducted some tests on sewage on a small scale at Dayton, Ohio, using lime and marl, as a conditioner, followed by ferric chloride. As yet no data have been published. It is reported that about 1000 lb. of marl per mil. gal. has been used, with ferric chloride about 125 lb. and hydrated lime about 1000 lb. A report on the use of this process for Dayton is under preparation by Buswell, Howson and Veatch for the city of Dayton.

Lewis Process.—The Lewis process was tested (147) experimentally at Atlanta, Ga., using ferric chloride, lime, Cottrell dust from the manufacture of Portland cement, and ferrous sulphate, in varying proportions. In the demonstration plant, with a flow of 500,000 gal. per 24 hr., the mixing chamber had a combined theoretical detention period of 22 min. and was divided into three units, the ferric chloride being fed into the first, the lime and Cottrell dust into the second, and ferrous sulphate into the third. The ranges of quantity per mil. gal. within which the materials were added were as follows:

Ferric chloride	70 to 225 lb. (60 to 62 per cent $FeCl_3$);
Lime	627 to 1450 lb.;
Cottrell dust	0 to 610 lb.;
Ferrous sulphate	62 to 125 lb. (based on weight in crystals)

The period of settling provided was about 60 min., with a flow of 500,000 g.p.d.; 40 min. with 750,000 g.p.d., and 30 min. with 1,000,000 g.p.d.

The results reported were as follows:

Period	Suspended Solids		5-Day B.O.D.		Detention Period Min.
	Influent p.p.m.	Per Cent Reduction	Influent p.p.m.	Per Cent Reduction	
A	141	76	116	77.2	
B	170	73	145	80	
C	187	81.5	125	67.5	60
D	190	67.9	85	57.8	
E	175	81			40

The amounts of chemicals used in the respective periods were not stated.

A Special Sewer Committee (148) reported that the tests failed "to demonstrate the practicability of filtering and heat drying the sludge," and further that "the sludge produced is about three times the volume of sludge from non-chemical sludge digestion plants. It is largely raw precipitated human excreta mixed with other waste matter and the precipitated chemicals used in the process."

The analyses of cost data presented by Parsons, Klapp, Brinckerhoff, Douglas and Potter, would indicate (147) that the chemical precipitation procedure was lowest in annual charges, either with 15 or 30 yr. bond financing. However, the Special Sewer Committee reported (148) that trickling filters, with separate sludge digestion, would be the cheapest (saving $38,000) and in the opinion of the Committee, the best available process. All the estimates omit any charges for royalty.

Diamond Alkali Company Process

The Diamond Alkali Company carried on some tests at Cleveland, Ohio, and Rochester, N. Y., on a procedure claimed by U. S. Patent 1,968,114, issued to C. N. Windecker. The essential claims were for the preliminary deodorizing of sewage and other wastes by admixing chlorine in an amount insufficient to sterilize, then admixing lime, slowly agitating, coagulating, and settling, and separately sterilizing the effluent and the solids. For the preliminary chlorination, from 10 to 20 p.p.m. of chlorine was proposed. A part of the solids was to be returned to the incoming sewage. Tests were made on a fairly large scale in an Imhoff tank at Rochester. It was proposed to remodel the Imhoff tanks at the Irondequoit plant for use by this process, but after consideration of the

results of the experimental work, this project was abandoned. Experiments were also carried on at Salem, Ohio, and Newark, N. Y. It is reported that the process has been in use at Butler, Pennsylvania since 1934.

Koller-Miller Process

Tests were made at Elmhurst, Ill., in 1933 by Koller, Miller and others, treating an approximate gallonage of 130,000 per day with a number of chemicals, including an alkali (lime or soda ash, or both), sodium aluminate, copper sulphate, and chlorine. The only information available is in U. S. Patent 1,997,302. The use of copper sulphate was stressed. No further work on this process has been reported, and apparently it has been abandoned by the H. A. Brassert Company, of Chicago, its original sponsors.

Putnam Process

A. R. Putnam has made tests at Valparaiso, Ind., on approximately 25,000 gal. per day, treating sewage with ferric chloride, lime and charred sludge. The procedure is described in U. S. Patent 1,915,240. A plant has been installed at the House of David, Benton Harbor, Mich., for a connected population of 800.

Chemical Precipitation Studies

Michigan.—Rumsey, Eldridge and Damoose have investigated (149, 150) coagulation with ferric chloride at Grand Rapids, with and without flocculation.

The first series of tests were made on the plant itself, using two of the four 70-foot square Dorr clarifiers, between January 18 and 28, 1933. The variation in removal figures suggest the necessity for a longer period of observation. No secondary treatment is provided at Grand Rapids, the sewage being given a 1.5 to 2.0 hour detention period in the Dorr clarifiers. For the test, the sewage was divided in a control chamber, one-half going to each pair of tanks. Tank No. 1 was untreated and Tank No. 3 used for experimental coagulation. Weirs at the outlet were placed to measure the flow, which was read hourly. Four different doses of 3.5, 7 and 10 p.p.m. of ferric chloride were applied, each over a period of several days. The average results show only a slight additional removal of suspended solids and B.O.D. over the removals obtained by plain settling. The results were:

Determination	Per Cent Reduction With Chemicals	Per Cent Reduction Without Chemicals
B.O.D.	34.4	31.9
Suspended Solids	66.2	51.4

Apparently the amount of ferric chloride added (maximum 83 lb. per

mil. gal.) was too low to effect a noteworthy improvement in clarification.

Eldridge and Damoose comment as follows:

"The results of this study were erratic. While the results show that the ferric chloride aided in the removal of suspended solids, at no time was there a visual difference in the clarification of the sewage passing through the two tanks. Subsequent studies indicate that much better clarification and suspended solids removal would have been obtained had it been possible to provide a flocculation period prior to settling."

Later a semi-portable experimental plant was set up at East Lansing with a coagulation tank of 900 gal. capacity and a sedimentation tank of 2,640 gal. capacity. The detention period for coagulation varied from 22 to 35 min., for settling, from 64 to 103 min. Ferric chloride varied from 35 to 285 lb. per million gallons. Twenty runs were reported in as many days. The results indicated that the removal of suspended solids increased with increasing amounts of ferric chloride up to at least 180 lb. per mil. gal., which resulted in the removal of about 90.0 per cent on two tests. The B.O.D. was considerably decreased, indicating the removal of organic colloids as well as suspended solids.

Later tests (143) on a laboratory scale and in an experimental plant handling from 18 to 45 gal. per min. compared ferric chloride, ferric sulphate and alum with plain sedimentation.

The Grand Rapids tests established:

1. The advantage of ferric chloride as a coagulant.
2. The optimum dose for Grand Rapids as about 1.5 gr. per gal. (214 lb. per mil. gal.).
3. The most effective settling period as from 1.5 to 2 hours.
4. The necessity of coagulation with slow stirring for at least 30 minutes.

Chemical Precipitation at Dallas.—The City of Dallas and the Texas Engineering Experiment Station jointly conducted laboratory investigations for nearly a year, followed by plant scale experiments. The Dallas sewage averaged around 400 p.p.m. suspended matter and B.O.D. The laboratory work consisted of several hundred runs in glass jars equipped with stirring apparatus. The chemicals used as coagulants were:

Ferric chloride,
Ferrous sulphate or copperas,
Chlorinated copperas,
Ferric sulphate,
Alum,
Aluminum chloride.

Each chemical was tested over a pH range from 2.0 to 13.0 by appropriate doses of sulphuric acid, lime and caustic soda. In addition, certain

auxiliary chemicals, such as chlorine, potassium permanganate, lignite, clay, etc., were used for certain runs. The results indicated that ferric chloride was the best coagulant for Dallas sewage, with the possible exception of aluminum chloride. Five grains per gallon (712 lb. per mil. gal.) or less produced a clear effluent with a considerable reduction in B.O.D., with the pH near 6.0 for best results.

The experimental plant consisted of an Imhoff tank remodeled and fitted with flight collectors and mixing chamber. A ferric chloride generator was also provided. Secondary units included anthracite filters, the effluent proving satisfactory for use in the chlorinators; Hays aeration unit, and a trickling filter unit. Based on the laboratory data, a maximum dose of 5 grains per gal. (712 lb. per mil. gal.) ferric chloride was applied to the raw sewage. Return of sludge aided the settling markedly. The operation of the ferric chloride generator required care, in order to produce all ferric chloride and no ferrous. Not all the chlorine applied is recovered as ferric chloride, but about 90 per cent conversions are striven for in order to reduce the cost of operation.

The Hays aeration unit and the sprinkling filter were operated on Imhoff effluent as a direct check on the efficiency of the chemical process.

Steel and Zeller state (145) that at Dallas ferric chloride was the best coagulating agent, closely followed by aluminum chloride. In both cases, however, reaction control to the acid side was essential for a minimum chemical dosage and cost.

An average removal of 77 per cent B.O.D. and 86 per cent suspended solids was claimed by the use of 700 to 1,500 lb. of chlorine and 200 to 400 lb. scrap iron per mil. gal. The equivalent ferric chloride generated and applied amounted to 650 to 1,200 lb. per mil. gal. The raw sewage had an average B.O.D. of 350 p.p.m. and suspended solids of 350 p.p.m. The Imhoff tank removal was 46 per cent B.O.D. and 54 per cent suspended solids. The costs were high, running from $25.00 to $50.00 per mil. gal.

Steel and Zeller concluded that at Dallas coagulation is probably too expensive, on account of the trade wastes and sudden fluctuations in sewage.

Chemical Precipitation Study at Aurora.—Sperry reports (151) a few studies made in 1934 at Aurora, Illinois, on the plant clarifiers using sulphate of alumina, anhydrous ferric chloride and semi-anhydrous ferric sulphate. The tests were made on the 2 or 3 hour peak period (11 A.M. to 2 P.M.). Owing to lack of an efficient flocculator, the results were somewhat irregular. The data given, as summarized in Table XIII, indicate quite appreciable improvement in percentage reductions by use of chemicals, but since the raw sewage was somewhat more concentrated when chemicals were used, during the peak period, the results cannot be

TABLE XIII.—*Specimen Tests at Aurora, Illinois. Improvement on Sedimentation by Addition of Chemicals*

Date 1934	Chemical Application			Raw Sewage in p.p.m.			Reduction in Per Cent		
	Hrs.	Kind	Gr. per Gal.	Susp. Matter	Oxy. Con.	5-day B.O.D.	Susp. Matter	Oxy. Cons.	5-day B.O.D.
Nov. 13	2 1/2	$Fe_2(SO_4)_3 9H_2O$	1.97	234	97	255	73.7	42.5	50.6
		None		160	80	240	46.8	22.2	34.1
Oct. 2	1	$Fe_2(SO_4)_3 9H_2O$	2.78	214	77	220	76.0	28.6	48.6
		None		156	74	210	55.6	20.3	39.5
Oct. 9	2 3/4	$FeCl_3$	1.16	324	96	292	81	38.5	57.2
		None		173	81	259	59.5	27.1	39.0
Oct. 17	3 5/12	$FeCl_3$	0.88	300	98	218	83	42.7	56.9
		None		165	81	154	61.2	22.2	25.2

Note: Average flow 7.5 m.g.d., except on Oct. 17, when 7.2 m.g.d.

compared directly with the percentage removals by plain settling, on weaker sewage. The conclusions were that further experiments were warranted.

Iron and Carbon Dioxide, Germany.—Jung has recently reported (152) the experimental treatment of a strong sewage in the Niersverband (Germany) containing industrial wastes. Electrolytic purification proved too costly when using iron electrode and simultaneous aeration. An "iron-carbon-dioxide" process was developed in which carbon dioxide was added to sewage in the presence of metallic iron (iron turnings) and aerated. Waste stack gases containing 10 to 15 per cent carbon dioxide and iron turnings can be used. Digester gas containing CO_2 can also be used. An iron dosage around 50 gm. per cu. m. of sewage (50 p.p.m.) was reported. The B.O.D. was reduced about 60 per cent.

Prior to Biological Treatment.—In England, chemical precipitation is still employed preliminary to biological purification. About 1908, Bolton was using 98 p.p.m. of lime and 28 p.p.m. of iron alum; Salford 170 p.p.m. of lime, 85 p.p.m. of copperas and about 120 p.p.m. of iron alum in treating sewage.

Downes has utilized (153) chemical treatment at Plainfield to lower the loading on trickling filters by nearly 50 per cent. The chemical dosage is varied to meet the changing flows and strength, at a maximum rate around 400 lb. of ferric coagulant per mil. gal. on the raw sewage, and 200 lb. per mil. gal. on the trickling filter effluent. The return of the chemically precipitated sludge from the final settling tank to the primary tank influent also proved effective, and is all that is required from midnight to noon. From noon on, additional chemical is added to the screened sewage. The average daily dose in the primary tank was about 252 lb. of commercial sulphate of iron (Calcoag) per mil. gal. The sludge was increased in volume about 30 to 50 per cent, and digested readily, with a minimum of odor. In the fall of 1934 experiments began on the use of chlorinated copperas, and in June, 1935, this coagulant displaced Calcoag.

At Atlanta, Ga., Singleton and Frith have been conducting experiments on precipitation by chlorinated copperas to relieve overloaded trickling filters. They have found that treatment with carbon dioxide prior to addition of iron coagulant has been of value in reduction of amount of coagulant required and has improved clarification.

Effect of Chemicals on Activated Sludge.—The sewage at Gastonia, N. C., is frequently colored by spent dye wastes from textile mills (154). At such times, ferric chloride solution (about 25 lb. ferric chloride per hour) is added to the raw sewage ahead of the activated sludge plant. The final effluent is said to be colorless and improved in quality by the use of ferric chloride.

At Phoenix, Arizona (155), the application of lime in the aeration and reaeration tanks is said to have controlled the bulking of activated sludge due to tomato seeds and peach wastes, but was ineffective in preventing bulking caused by phenol from gas works waste.

Clark (156) indicates that bulking difficulties in an activated sludge plant were decreased by the preliminary addition of 54 to 66 lb. of ferric chloride per mil. gal. of sewage.

Mechanical Filtration of Sewage Effluents

Streander (157), Imhoff (158), Zack and others have advocated following chemical precipitation by filtration, either by rapid filters or the Laughlin magnetite filter. The data on performance and cost as yet are not definite enough to indicate the value of such a procedure. Gould (159) and Donaldson (160) consider that shallow filtration or straining may have value as a stop-gap for irregularities in performance and in reducing the required settling capacity of settling or chemical precipitation tanks.

Recently published tests on the chemical dosage in relation to settling and filtering of raw sewage at Coney Island by Rudolfs, Brendlen and Carpenter (128) show the effect of lime and ferric chloride with a somewhat strong, stale sewage (5-day B.O.D., avg. 150 p.p.m.). Lime was added before the iron. The tests covered a range of lime (as CaO) from 0 to 122 p.p.m. and of ferric chloride (as Fe) from 0 to 14.9 p.p.m. A minimum of 7.5 p.p.m. of iron and a pH of 9.2 to 9.5 was required, thus needing 45 to 50 p.p.m. of CaO. The comparison of cost between the Laughlin filter and plain settling is obscured by the sole consideration of chemical cost. The detention period in both tanks was about 2 hr. and the filtration rate about 2 gal. per sq. ft. per min. It is stated that a reduction of B.O.D. up to about 70 or 75 per cent can be easily obtained and that the cost of removal of each additional percentage or p.p.m. of suspended solids or B.O.D. becomes greater the higher the degree of purification obtained, until a point is reached where chemical precipitation with or without filters becomes economically unjustified.

The Degree of Treatment Accomplished by Chemical Precipitation

All investigators of chemical precipitation of sewage agree in the conclusion that very little, if any, of the dissolved organic solids can be removed by the addition of chemicals. In fact, it is generally considered to be impossible to remove all of the colloidal matter by chemical precipitation. Thus effluents from such treatment usually are not sparkling clear but contain a fine turbidity or a slight opacity caused by the most highly dispersed insoluble matter. Because of this limitation, chemical precipitation is inferior to biological oxidation in the degree of removal of B.O.D., organic nitrogen, organic carbon and ammonium compounds.

In the earlier experience with lime as a coagulant, it was found that addition of large amounts, producing caustic alkalinity, might result in peptization of insoluble solids and thus an increase of organic matter, over that found in an effluent from plain sedimentation. In more recent work, with the control of the pH, the use of small amounts of lime, and the dependence upon ferric hydroxide for flocculating, the peptizing or dissolving effect has not been encountered. Ferric chloride or sulphate may remove a small amount of soluble organic matter or ammonium compounds by adsorption or by formation of complex iron salts, similar to those reported by Miller in his studies of the removal of organic coloring matter from water.

The residual organic matter remaining in an effluent from chemical precipitation of sewage usually requires a considerable amount of oxygen for stabilization. Even with dilute sewage, the effluent may have a 5-day B.O.D. of 25 p.p.m. or more, whereas an activated sludge effluent from the same sewage would probably have a B.O.D. less than 12 p.p.m and a trickling filter effluent possibly 15 to 20 p.p.m., with, however, a substantial amount of nitrate nitrogen to satisfy a large part of the oxygen demand and thus prevent anaerobic conditions. Chemical treatment, however, does not make nitrate and adds no dissolved oxygen except that introduced physically by mechanical agitation.

Degree of Treatment.—The percentage reductions of B.O.D. and suspended solids by various types of chemical treatment cannot well be compared from place to place for sewages of variable concentration. As in other types of sewage treatment, higher percentage reductions are possible with concentrated sewages than with weak. This fact was shown by Zack (123) for the Laughlin Process at Dearborn and Coney Island. The percentage reduction of B.O.D. varied from 40 per cent with sewage of 50 p.p.m. B.O.D. up to 80 per cent with 200 p.p.m. Several results exceeded 80 per cent slightly, with sewage of 250 to nearly 400 p.p.m. 5-day B.O.D.

Hendon presents (135) the following results:

Sewage	B.O.D., 5-Day		
	Raw	Effluent	Per Cent Reduction
	Parts per Million		
Shades Valley (Weak)	35	9.0	74.3
Shades Valley (Strong)	120	8.0	93.3
Tarrant City, Experimental	140	8.0	94.3
Ensley, Experimental	300	15.0	95.0

The increasing percentage reduction with stronger sewages is shown clearly by these results.

Effect of Increasing Coagulants.—An increasing percentage removal of B.O.D., up to a limiting value, may be accomplished by an increase in the amount of coagulants applied, particularly in the case of ferric coagulants. The largest amounts of ferric coagulants applied in the various recent studies of chemical treatment were undoubtedly those used in the investigations of the Guggenheim Process at Chicago, in which the following amounts were used, with correspondingly high removals of B.O.D., as shown by the settled effluent prior to zeolite filtration.

Month 1933	Lb. $Fe_2(SO_4)_3$ per M. G.	Per Cent Red. B.O.D.
March	960	76.2
April	930	80.2
May	1140	83.6
June	805	85.2
July	730	83.0
August	778	85.8
September	570	84.8

These amounts of ferric coagulant are considerably greater than those used in other investigations, and, consequently, the percentage reductions of B.O.D. were about the maximum attained by chemical precipitation.

In studies of the Laughlin Process at Coney Island, Rudolfs, Brendlen and Carpenter (122) report the following variation in percentage reduction of B.O.D. and suspended solids with various quantities of ferric salts:

Effect of Increasing Coagulants on Reductions of B.O.D. and Suspended Solids. Coney Island—Effluent Not Filtered

Lb. per M. G.		B.O.D.—5-Day			Suspended Solids		
Lime as CaO	Ferric Chloride as $FeCl_3$	Raw p.p.m.	Eff. p.p.m.	Per Ct. Redn.	Raw p.p.m.	Eff. p.p.m.	Per Ct. Redn.
0	0	138	103	25	117	73	38
253	112	149	52	65	93	28	70
458	182	162	68	58	161	47	71
515	273	152	53	65	124	22	82
1015	361	138	30	78	138	10	93

These results show that excessively large amounts of chemicals were required to obtain a B.O.D. reduction exceeding 65 per cent.

Effect of Different Sewages.—The character of sewage treated has considerable influence on the reduction of B.O.D. obtainable with a given

chemical dosage. The Coney Island sewage, for which results are presented in the preceding table, has not yielded as high percentage reductions of B.O.D. as the Dearborn sewage, for equal amounts of chemicals.

In laboratory tests in the Main Laboratory of The Sanitary District of Chicago, it was found that appreciably higher percentage reductions of B.O.D. could be obtained with West Side sewage than with 39th St. sewage, even though the raw sewages were almost identical in B.O.D.

Rudolfs has also investigated this variation in types of sewage, with respect to their amenability to chemical treatment. His results have not as yet been published.

It is apparent that it is not safe to generalize on the degree of B.O.D. removal that can be obtained with all sewages of the same B.O.D. content, and treated with identical amounts of chemicals, but that each sewage is a specific problem requiring investigation. Research on the reasons for these variations would be of value.

Effect of Period of Flocculation.—In the recent studies of chemical treatment, it has been recognized that the formation of a dense, rapidly-settling floc is of importance. In purification of water, the use of mechanical flocculators has been common practice for many years, and consequently the types of flocculators used in sewage treatment are similar to those used in water purification. These include fish ladder flumes, vertical-shaft paddles, horizontal-shaft paddles and spiral flow aeration. The period of flocculation varies from 10 to 30 minutes. After the floc has been built up, care must be taken to prevent its disintegration by agitation before the flocculated sewage enters the settling tank.

Effect of Period of Settling.—Chemically-flocculated sewage solids settle rapidly if the floc is well formed, but the frequent variations in character and concentration of raw sewage make it difficult to obtain a satisfactory floc continuously. It is, therefore, unsafe to use a very short period of settling. However, a detention period of only 1 or 2 hours has been provided in several recent installations (Coney Island, Perth Amboy, Shades Valley, Dearborn), based on designed capacity. The use of filters or strainers for the effluent (Dearborn, Perth Amboy, Streander) has been of value for retention of finely divided floc which otherwise might escape with the effluent.

Secondary Treatment.—Secondary biological treatment by trickling filters for chemically precipitated and settled effluents has been investigated experimentally at Atlanta (Lewis Process), and Dayton (Travers "Purification Systems"). The data are quite inadequate to determine filter loadings or efficiencies. The larger scale work at Plainfield, N. J., has been described (*vide supra*).

The use of mechanical filters has been investigated, as stated above,

at Dearborn and Coney Island. Such filters are not biological oxidation devices, but act as mechanical strainers.

Sludge from Chemical Treatment

Quantity of Sludge.—Chemical precipitation results in an increased amount of sludge over that produced by other processes in which no foreign solids are introduced. The use of aids to coagulation such as lignite, marl, Cottrell precipitator dust, clay, ground limestone, diatomaceous earth or the like, increases the amount of solids in the sludge. When large doses of lime are used to produce highly alkaline coagulation, additional sludge is precipitated, depending on the hardness of the sewage. Every pound of lime added to water to soften it or to sewage produces more than three times its weight of calcium carbonate sludge (161).

Editor's Note. Dr. Buswell has requested that the following remarks be inserted:—

"(1) On the assumption that plain sedimentation produces a 35 per cent purification and chemical coagulation a 70 per cent purification, one would expect twice as much organic matter in the sludge from chemical precipitation.

(2) Sludges of 10 per cent solid content may be readily expected from chemical precipitation. On this basis, the total volume of sludge obtained by chemical precipitation would be somewhat less than obtained by plain sedimentation.

(3) The sludge can be handled on sand beds direct or on Oliver filters.

(4) With proper chemical quantities the sludge will decompose in the open air without nuisance.

(5) The sludge will decompose normally under anaerobic fermentation yielding an equivalent amount of methane and a much smaller amount of CO_2 and hydrogen sulfide. Its decrease in the amount of CO_2 and H_2S are due to absorption by the lime and iron respectively."

The volume of sludge produced by the use of ferric salts, either alone or in combination with small amounts of lime, is not well defined, because of lack of data on the moisture content of such sludge. Some data have, however, been derived from the following sources:

North Side Works (The Sanitary District of Chicago)—

> In the chemical precipitation stage of the Guggenheim process as demonstrated at the North Side Works, with suspended matter running from 119 to 150 p.p.m. in the raw sewage, from 1450 to 2080 lb. of dry solids were recovered as sludge from the precipitation, where from 262 to 440 lb. of lime and from 570 to 1140 lb. of ferric sulphate were used per mil. gal. of sewage. The ratio of sludge to suspended solids removed varied on a dry basis from 1.23 : 1 to 2.1 : 1.

According to Enslow (161) Hendon claims that with chlorinated copperas 10 per cent more sludge was pumped than shown by the removal of suspended matter.

Disposal of Chemical Sludge.—Until recently, no chemical precipitation plant in the United States offered ultimate disposal other than by dumping at sea (Providence) or by filter pressing and dumping on land (Worcester). The latter had not proven entirely satisfactory because of the raw sewage solids present. At Dearborn, Mich., vacuum filtration was practiced, the cake being dumped at the sewage works. Recently, a Herreshoff dryer and incinerator has been installed. In the tests on the Guggenheim process, filter pressing with vacuum filters, followed by drying and roasting in a rotary kiln, was tried, with the thought of regenerating the iron salts recovered. However, the presence of lime salts interfered with the efficiency of the process.

At Perth Amboy, N. J., dewatering on vacuum filters, with disposal in the municipal incinerator, is proposed. At Coney Island, N. Y., a vacuum filter is planned, with dumping of the cake at sea.

The procedure of dewatering on vacuum filters and incineration is available for consideration in most sewage works of some size. Practically no working data are available on chemical sludges. Most of the practical work on incineration of sludge has been carried on at the West Side Works of The Sanitary District of Chicago. A 40-ton plant is being erected at the Calumet Sewage Works. The Sanitary District investigation was almost wholly on activated sludge, either alone or mixed with fresh or digested sludge. Vacuum filtration tests have been made at Columbus and Baltimore on straight digested sludges. Spray drying has been tried at Plainfield, N. J. Inherently, there should be no difficulty with dewatering and incineration if the proper apparatus is adequately designed and efficiently operated.

Prior to the use of vacuum filters on activated sludge at Milwaukee in 1922, plate filters were the type commonly used in the United States or abroad in filtering sewage sludge, either with or without chemical precipitation or conditioning. In the United States, plate presses for sewage sludge were abandoned with the passing of the chemical precipitation plants at Providence, R. I., and Worcester, Mass. Vacuum filters are becoming more popular. In Great Britain, plate presses are still in use at Glasgow and Bradford.

Incineration of Sludge.—Incineration of sludge from the lignite (see Degener Process *supra*) process of sewage treatment was practiced in Germany in 1909 and prior thereto (162). In the lignite process, dry, powdered lignite and iron salts, or salts of iron and alumina, were added to the sewage. The resulting sludge, containing 95 per cent water, was filter-pressed to 60 per cent and then pressed into briquettes for burning. The combustion of mixed screenings and sludge was practiced. At Charlottenburg, Germany, coal was used in burning ordinary sludge but it proved expensive.

At Frankfort-on-the-Main, mixtures of one part moist sludge and three parts rubbish were burned in a crematory at temperatures from 1,212 to 1,652 deg. Fahr.

Owen describes (126) the incineration equipment at Dearborn, Michigan, with details on the 90-day test. The equipment includes (163) a Nichols-Herreshoff incinerator with an outside diameter of 16 ft. 9 in. and an outside height of 17 ft. $3\frac{3}{4}$ in., provided with 6 hearths. It is designed to handle daily 50 tons of sludge cake containing 65 per cent water and 35 per cent solids, of which 65 per cent was assumed ash and 35 per cent combustible (at 10,000 B.T.U. per lb. dry). In the 48-hr. test, 118.6 tons of sludge cake were handled; in the 90-day test, 2,258 tons. The costs reported per 24 hours range from $0.17 to $0.96 per ton of sludge cake, to which Owen recommends that $0.40 be added to cover amortization, depreciation and interest. In general, the costs as reported ran from $0.17 to $0.34 per ton of sludge cake, exclusive of fixed charges, the high figure being due to a small tonnage (3.46 tons per 24 hr.) burned. Oil was used on a number of days. Owing to the relatively small sludge production, incineration approaching capacity was possible only on a few days of the 90. On most of the days, sludge was burned about 8 hours per 24 hours. The ash averaged about 15 per cent by weight of the sludge cake. The contract cost of the incinerator and auxiliary equipment was $56,000.

Recent Comment.—Eddy-Greeley-Gregory say (164) that the handling and the disposal of chemical precipitation sludge offers one of the most serious problems in connection with chemical treatment of sewage. "Such sludge contains a large proportion of highly putrescible sewage matter. While fermentation or putrefaction of this matter may be delayed by the lime used in dewatering the sludge, it is certain to start to decompose shortly in such a manner as to produce offensive odors, especially when dumped in large quantities. It cannot be spread upon the land or put into dumps without serious danger of causing justified complaint."

Costs of Sludge Disposal.—Very little recent information is available on the cost of pressing and disposing of chemical sludge, but data from Worcester and Providence of some years ago may serve to define the approximate cost of such disposal.

When the chemical precipitation sewage works were in service at Worcester, Mass. (165), the sludge collected was treated with lime and dewatered for a number of years in Bushnell type presses. There were four presses, each containing 125 plates. Approximately 45 min. at a pressure of 70 to 80 lb. per sq. in. was required to produce a cake, and 15 min. to clean a press. The filter pressing of sludge was discontinued in April, 1917. Thereafter, the sludge was dried on sand beds.

Data regarding the filter pressing of sludge at Worcester from 1899 to 1917 inclusive show from 3.9 mil. gal. to 52.6 mil. gal. of wet sludge pressed with a solid content ranging from 2.99 to 10.22 per cent. The press cake ranged from 3,033 to 25,088 tons per year, with a solid content ranging from 23.7 to 31.7 per cent. The dry solids varied from 919 to 7,608 tons per year, or from 0.91 to 1.98 tons per mil. gal. of sewage treated. The quantity of lime used to treat the sludge varied from 11.1 to 58.4 lb. per 1,000 gal. of sludge pressed, with an average of 43.5 lb. With the exception of the few months of operation in 1917, the cost of filter pressing ranged from $3.39 to $5.02 per ton of dry solids.

At Providence, R. I. (166), chemical operation was suspended in September, 1934. This was the only plant in the United States where filter cake was barged to sea and dumped. The sewage flow at Providence during the 12-year period from 1922 to 1933 inclusive averaged 32.4 m.g.d. The solids were precipitated with lime. After removal from the sedimentation tanks the sludge was conditioned with an average of 44.7 lb. of lime for each 1,000 gal. of sludge. The sludge was then forced under a pressure of 40 lb. per sq. in. into one or more of 16 Johnson presses. Each press contained fifty 36-in. by 36-in. plates, covered with army duck, 40 in. wide and weighing 11 oz. per sq. yd. The time required to fill a press varied from 40 min. to 1½ hr. The rate of filtration ranged from ½ to ¾ lb. of sewage solids per square foot of filter cloth per hour. Approximately 1,800 lb. of sludge cake was removed from a press during each cleaning period of about 12 min. The cake varied in thickness from ⅞ to 1¼ in., and contained from 65 to 80 per cent moisture, averaging 75 per cent. The cake, in batches of 55 tons, was hauled in a double-bottomed scow for a distance of 20 miles and dumped. Thirty trips were made yearly, at a cost of about $100.00 per trip.

Digestion of Chemical Sewage Sludge

In recent years, both laboratory and field experiments have been conducted to determine the effect on sludge digestion of coagulants used to flocculate the solids in raw or treated sewage. Laboratory experiments conducted by Rudolfs, Setter and Baumgartner (167) indicated that the addition of 1 to 4 p.p.m. of $FeCl_3$ did not appreciably affect sludge digestion. However, when larger quantities of $FeCl_3$ were used, digestion was retarded, but the total quantity of gas produced was greater. Setter (168) confirmed these conclusions, and also found that relatively large quantities of $FeCl_3$ are decidedly toxic to the organisms present in fresh sewage solids, whereas 5 p.p.m. or less have very little effect. Sodium aluminate in a concentration of 5 p.p.m. was found to stimulate digestion. In experiments where 5 p.p.m. of alum (169) was added to raw sewage containing 200 p.p.m. of suspended solids, digestion was retarded.

Experience at Grand Rapids, Mich.—Tests were made for 20 days in one clarifier and digester of the Grand Rapids, Mich. sewage works (150), adding from 3 to 10 p.p.m. of ferric chloride to the raw sewage. The ferric oxide content of the sludge averaged 4.1 per cent. The dry solids in the sludge deposited in 8 days in the treated tank were 17.8 per cent greater than in the untreated tank. The sludge was pumped to a heated digestion tank, with an increase in gas yield of 15 per cent. The tests as reported are for too short a term to permit definite conclusions, but apparently the use of ferric chloride was not injurious to the digestion process.

Experience at Plainfield, N. J.—During the experiments recently conducted by Downes (153) at Plainfield, N. J., on the treatment of raw sewage and trickling filter effluent with ferric sulphate (*loc. cit.*), the sludge collected in the primary and final settling tanks was from 30 to 50 per cent greater than the amount produced without chemical treatment. Downes states that "the combined sludge digests readily with a minimum of odor production. The chemically produced sludge mixtures digest without the usual acid stage of digestion, experienced when digesting ordinary sludges. Aside from this apparent advantage, it digests as does ordinary sludge."

If coagulants are to be used for long periods of time at plants where the sludge is digested, it will be necessary to provide additional digestion tank space to take care of the increased quantity of solids. Furthermore additional volume will be needed if digestion is retarded by the use of large quantities of coagulants.

Editor's Note. Dr. Buswell has requested that the following remarks be inserted:—

"We disagree with this statement. On account of the large amounts of inert material added, the sludge will be found in a handleable condition as soon as the gas production has ceased. The gasification is practically complete in 5 or 10 days in heated tanks."

Effect of Water Softening Plant Sludge.—Many water softening plants discharge the sludge into city sewers, which ultimately bring the sludge to a treatment works. In small towns, the sludge solids from water softening may be very much greater than those from the sewage. Eldridge (170) found in the laboratory that the presence of such lime sludge in amount 75 per cent by dry weight of sewage solids slowed up the digestion, and at 150 per cent, sludge digestion did not start until after 18 days.

Editor's Note. Dr. Buswell has requested that the following remarks be inserted:—

"The publication cited by the Committee reports only preliminary laboratory experiments. A later report (Bulletin No. 40, Michigan Engineering Experiment Station) gives extensive data on plant scale experi-

ments on the disposal of water softening plant sludge at the sewage treatment plant. This final report appeared in November, 1931.

The conclusions reached are as follows:

'These studies show conclusively that the lime sludge from the municipal water filtration plant at Grand Rapids can be disposed of through the sewage treatment plant. There is no apparent reason to believe that this method of disposal is not applicable to other similar installations.

One of the requirements for the success of this method is the installation of continuous sludge removal equipment for the settling basin at the filtration plant. This equipment should deliver a constant quantity of lime sludge to the treatment plant which in amount should approximately equal twice the weight of the sewage solids. Judging from the results of this study the disposal plant can handle this quantity, and perhaps more, without injury to the biological processes involved in the treatment of sewage.

The studies reported herein have lead to the following major conclusions concerning the effect of this lime sludge on the treatment plant operation:

1. Digester Operation.
   (a) Gas production started much more rapidly in the initial stages of sludge digestion with the lime than without.
   (b) The rate of gas production and the volume of gas produced was greater with the series when lime sludge was present.
   (c) The digested combined sludge has a much higher solids content than digested normal sewage sludge.
   (d) The decrease in volatile matter content was quite parallel in both cases.
   (e) The only mechanical difficulty encountered was an increase of the load carried by the digester mechanism.
2. Influent and Effluent.
   (a) Lime sludge had very little effect on the effluent of the primary treatment. The pH, alkalinity and suspended solids were practically the same as when lime sludge was not present.
   (b) The raw sludge from the primaries had a much greater solids content and a higher pH.
3. Sludge Drying and Fertilizer Value.
   (a) Sludge drying was accomplished in the same manner as with normal sludge and at about the same rate.
   (b) The lime sludge acted as a diluent on the fertilizer value but adds a certain amount of material for the correction of soil acidity.

4. Sewerage System.

No trouble was experienced with stoppage in the sewerage system.

5. Sludge Capacities.

Larger digester capacity and sludge areas were required due to the increase in solids handled. This additional digester capacity was not proportional to the quantity of sludge handled.' "

Effect on Imhoff Tank Operation.—Imhoff (158) stated in 1914 that Imhoff tanks work satisfactorily on sludge from chemical treatment, leaving a sludge practically odorless and easily drainable. He roughly estimated 67 per cent more sludge digestion space was required.

At Fredonia, N. Y., Heubi noted (171) that foaming in the Imhoff tanks caused by acid cannery wastes could be prevented by applications of lime during the canning season. During the tomato season (August and September) 150 to 200 lb. of lime are used daily. The yearly average flow has run from 666,000 (1932) to 850,000 (1931).

An oil boom caused the Imhoff tank plant to be overloaded (172) at Oklahoma City, resulting in foaming. Prechlorination and final chlorination helped, but ferric chloride prepared from scrap iron and chlorine (see Scott-Darcey process) made a decided improvement.

Chemical Conditioning of Sludge

In sewage treatment, there are two distinct phases; first, the treatment of the liquid, and, second, the treatment or handling of the sludge or solids deposited. In a review of the Chemical Treatment of Sewage, the Committee considers that some attention, even though relatively brief, should be given to the value of chemicals in conditioning sludge, and, in particular, prior to vacuum filtration.

Prior to Vacuum Filtration.—In the earlier days, sludge conditioning, when using plate presses, was largely confined to the use of lime or acid. In the more recent period since 1920, with the development of the activated sludge process and the search for economies in the operation of sewage treatment works on a large scale, other lines of dewatering were sought, of which the use of rotary vacuum filters, with a suitable conditioning chemical or chemicals, has proven the most effective.

Laboratory work conducted at Urbana, Ill., by Hatfield (173), at Milwaukee by Copeland and Heisig (174) and at Chicago by Mohlman and Palmer (175) emphasized the necessity of suitable conditioning of activated sludge prior to filtration. Wilson supplemented this work by noting the possible use of heat and emphasizing the value of pH control. Wyman in Pasadena, Fugate at Houston, and others added to the general knowledge, but it was not until the discovery by Palmer of the increased

conditioning effect of the trivalent iron salts, such as ferric chloride and ferric sulphate, that a real advance was made in dewatering activated sludge (176).

In 1930, interest was aroused in the application of vacuum filters to dewatering fresh sludge and mixtures of activated and other sludges, to determine if digestion and open air drying of sludge might not be eliminated. Tests were begun by The Sanitary District of Chicago which have developed into large scale work, coupled with the study of incineration of the dewatered sludge.

Tests at Chicago (177) demonstrated that mixtures of activated and settled sludge, treated with 5 to 7 per cent of ferric chloride (based on dry sludge solids), filtered readily at pH 3.8 to 4.2, giving around 3 lb. per sq. ft. per hr. of dry sludge.

At Columbus, Ohio, Baltimore, Md., and Cleveland, Ohio (178), tests have been made on digested sludge. Jones concludes, at Cleveland, that on Imhoff or separately digested sludge "at least 8 per cent ferric chloride will be required to produce an output of between 4 and 5 pounds per sq. ft. of filtering area per hr. on a year round basis." The best results were obtained with a filter feed around a pH of 6.3 to 6.5 for separately digested sludge.

At Columbus (178), Imhoff tank sludge was filtered with ferric chloride alone and also in combination with lime. The cake produced averaged around 70 per cent moisture and a rate from 4 to 5 lb. dry solids per sq. ft. of filter area per hr. was not difficult to maintain.

Results from filtering chemically precipitated sludge at Dearborn from November, 1933, to April, 1934, gave (125) an average of 7.5 lb. dry solids per sq. ft. per hr., using 82 lb. lime (CaO) and 19 lb. ferric chloride per 1,000 gal. sludge. The wet sludge averaged 90.7 per cent moisture and the cake 67 per cent. During this period a rather large amount of ferric chloride was used for coagulation, which may explain the low amount used for conditioning the sludge.

Keefer and Cromwell made tests (179) at Baltimore on a Genter and an Oliver filter, chiefly dewatering digested sludge. On the Genter filter, with digested sludge, from 3.54 to 13.83 per cent of ferric chloride was used, with an output from 2.1 to 23 lb. of dry solids per sq. ft. of filter area per hr. The moisture in the cake averaged 76.7 per cent. The capacity with semi-digested sludge was very much less. With raw sludge, ferric chloride was not satisfactory. With paper pulp, lime and copperas, the output was low, and the cost high.

On the Oliver filter, the ferric chloride was varied from 3.8 to 8.1 per cent, with a maximum output of 11.5 lb. dry solids per sq. ft. of filter area when using 6.8 per cent of ferric chloride. The moisture in the cake averaged 74.8 per cent. For estimating purposes, 8 per cent of ferric

chloride was assumed to be required, with a production of 14 lb. dry solids per sq. ft. per hr.

Chlorinated copperas worked well on digested sludge. With about 10 per cent of chlorinated copperas, an output of 7 lb. dry solids per sq. ft. per hr. could be obtained.

Ferric chloride ($5\frac{3}{4}$ per cent) and lime (14 per cent) showed an output about 13 or 14 lb. dry solids per sq. ft. per hr.

Comparative estimates indicated that with local chemical costs chlorinated copperas was the cheapest conditioner.

Keefer noted (180), however, that in the winter higher capacities of filtration were obtained with less coagulant than in the summer.

At Hagerstown, Md., Donaldson found (181) that in an activated sludge plant, on mixed sludges, a vacuum filter was operated with 9 lb. CaO per 100 lb. dry solids (pH 11 before filtration) and 3 per cent paper pulp suspension. This did not prove satisfactory, averaging only 0.6 lb. per sq. ft. per hr. of dry solids. Improvement was made by adding ferric chloride first and then milk of lime to pH 11.5, making a cake averaging 82 per cent moisture, with an output of 1.97 lb. per sq. ft. per hr. of dry sewage solids. Sludge conditioning chemicals averaged 9.4 per cent CaO and 5.5 per cent $FeCl_3$ on the dry solids basis.

Tests have also been made on various sludges, mostly digested, at Salem, Ohio; Los Angeles, Calif.; North Toronto, Ontario. Chemically precipitated sludges were dewatered at Winston-Salem, N. C., Dearborn, Mich., Oklahoma City, and at the Guggenheim Brothers experimental plant at the North Side Treatment Works at Chicago.

Although this work has indicated that careful study must be given to each sludge, with laboratory control and study of the pH, certain lines of procedure stand out. With activated sludge, ferric chloride has proven most effective as a practical coagulant. With digested sludge, as at Baltimore and Cleveland, the use of ferric chloride has proven most effective, with chlorinated copperas running a close second at Baltimore. With digested sludge at Columbus and Chicago (182), the use of lime with ferric chloride proved most effective.

Enslow in 1933 summarized (183) the requirements in general terms for conditioning prior to vacuum filtration, as follows:

Sludge	Ferric Chloride, Per Cent	Filter Cake	
		Moisture Content Per Cent	Yield Lb. per Sq. Ft. per Hr.
Activated	4 to 6	79 to 82	2 to 6
ctivated plus settled	4 to 6	79 to 82	2 to 6
gested	4 to 9	76 to 80	6 to 9

These values are subject to some revision in view of more recent data, particularly on digested sludge.

Enslow claims that the addition of about 10 per cent lime reduces the dosage of ferric coagulant to about 4 per cent. This does not appear to be a general rule, as lime was not helpful at Chicago on activated sludge, alone or mixed with fresh sludge.

Elutriation of Sludge.—Genter summarizes (184) the characteristics of colloids, particularly those in sewage. He indicates the value of elutriation for removal of soluble putrefactive products in sewage sludge, as reducing the amount of ferric chloride required. The optimum point for maximum rates of settled and elutriated settled and digested Baltimore sludges is approximately that of the iso-electric point of colloids containing protein, i.e., 4.7. Chemical de-ammoniation may be accomplished (185) by the use of formaldehyde, with or withour prior mixing with formalin, or by chlorine with sludge elutriation.

Keefer and Kratz (186) give field data concerning the effect of elutriation of digested sludge on filtration. Up to a certain point (roughly, 2 volumes of water to 1 of sludge), a saving in coagulant resulted, and a higher filter output. Ferric chloride was most efficient, next in order being chlorinated copperas, Calcoag and ferric sulphate. The sludge and the water were mixed, and then settled from 17 to 48 hours (4 to 6 hr. possibly will suffice). At Baltimore, using 2 volumes of water to one of sludge in 2 equal stages, the elutriate is estimated at 292,000 gal. (73,000 lb. of dry solids) per day, has a 5-day B.O.D. at 20° C. of 158 p.p.m., contains 270 p.p.m. of suspended solids and 251 p.p.m. of amino-ammonia nitrogen and may be satisfactorily treated by return to the raw sewage, which averages 96 m.g.d., with a B.O.D. of 249 p.p.m.

Chloride versus Sulphate Ions.—The claims and counter claims of various investigators with regard to the advantages of different ferric salts have resulted in some confusion (1). However, ferric chloride seems definitely established as the superior sludge conditioner. Keefer and Kratz (186), working with digested sludge, found that one pound of ferric chloride ($FeCl_3$) was equivalent to 2.24 pounds of chlorinated copperas ($FeSO_4 \cdot 7H_2O + Cl$), or 2.44 pounds of ferric sulphate, $Fe_2(SO_4)_3$. On the basis of equivalent iron, 1 pound of $FeCl_3 = 1.93$ pounds $FeSO_4 \cdot 7H_2O + Cl = 1.23$ pounds $Fe_2(SO_4)_3$. Since the iron content of a coagulant is often considered as the evaluating factor, it seems inconsistent that 1 pound of iron in $FeCl_3$ would do the work of practically 2 pounds of iron in $Fe_2(SO_4)_3$. Genter (184) explains this paradox by the fact that the negative chloride ion, being monovalent, does not act against the discharging effect of the trivalent ferric action as does the negative sulphate ion which is bivalent. This explanation appears tenable as similar results were noted at Hagerstown, Md., and Gastonia, N. C., and is most likely applicable to the conditioning of sewage sludges in general.

This phenomenon may not apply to the coagulation of waters or weak sewages. Craig and Bean, experimenting on water at Providence with ferric chloride, chlorinated copperas and ferric sulphate, observed (187) that they were all within 10 per cent of equal value when compared on a basis of iron content. Conversely, Miller, using chemically pure chemicals and distilled water in studying the effects of anions upon properties of alum floc, found (188) that sulphate ion had a stronger coagulating effect than the chloride ion.

Prior to Drying on Sand Beds.—Applied to sludge before drying on sand beds, a conditioner may be helpful but is likely to be too expensive except in unusual cases. The dosage may approximate 2 to 6 lb. of ferric chloride per 100 lb. of dry sludge solids, and alum somewhat higher. Ferric sulphate and chlorinated copperas appear to be intermediate.

Chemical Sludge as Fertilizer

Sludge from chemical precipitation processes of sewage treatment does not seem to have been attractive for agricultural purposes at any time during the last 50 or 60 years in England or the United States. In England, the sludge, loaded with lime, was refused by agriculturists. The large plants like London and Glasgow found it economically advantageous to dump the sludge at sea. The small plants for years have ploughed press cake into the soil as a means of disposal, or otherwise piled it up. In the United States, at Worcester, Mass., however, considerable quantities of the pressed sludge were taken away by farmers. Leipzig at one time used ferrous sulphate, but the iron made the larger quantities of sludge useless as fertilizer (189).

Use of Chemicals for Industrial Waste Treatment

For over forty years chemicals have been utilized in treating industrial wastes of various types, particularly in England in the Midlands, where various textile and wool scouring industries abound. The reports of the West Riding of Yorkshire Rivers Board, under the guidance of the late Dr. H. M. McLean Wilson and his successor, Dr. John H. Garner, contain many references of interest. As joint authors, Wilson and Calvert (190) discuss chemical precipitation in industry in English practice in great detail. They say, "the choice of a proper precipitant and the amount to be used depend upon the nature of the liquid to be treated and should always be decided from the result of laboratory experiments." Instances are cited of the use of the commoner precipitants, lime, sulphuric acid, alumino-ferric or sulphate of alumina, ferrous and ferric salts.

During recent years, the application of chemical treatment to industrial wastes has become more general in the United States, particularly for seasonal industries, such as canning of vegetables. The increase in

Wisconsin of vegetable canneries equipped with chemical treatment, from 18 in 1930 to 41 in 1935, is significant.

A general survey of industrial wastes is given (191) by Wishart and Lovett from a British viewpoint, indicating the chemicals more commonly used for various industries. Sierp (192) and Bach (193) review chemical treatment, with comments on American practice, noting that "single stage precipitation processes tried in America seem uneconomical on the large scale and are not suitable to replace biological treatment."

Acid Iron Wastes.—Coburn describes (194) the use of lime for neutralizing acid-iron wastes from a steel mill, but concludes recovery of sulphate of iron will be more satisfactory and economical in the long run.

Acid Mine Drainage.—Mine drainage in West Virginia is generally acid, and may vary from 500 to 1,000 gal. per day per acre of coal exhausted. Carpenter and Herndon indicate (195) that chemical neutralization of acid mine wastes produces too large a volume of sludge and is too expensive to be economically feasible.

Beet Sugar Factory Wastes.—Eldridge and Theroux review (196) the application of chemical treatment to beet sugar process waters, beginning with 1901, and including the use of

Lime,
Brown coal with alum and ferrous sulphate,
Brown coal and caustic soda with lime,
Clay.

In many cases there was re-use of treated water. The procedures did not remove odors in general. The effluents at times fermented and made trouble in re-use. Eldridge and Theroux ran laboratory tests with lime alone (400 to 1,000 p.p/m., optimum 500) and lime (200 to 1,000, optimum 600 p.p.m.) and ferric chloride (50 p.p.m.). There was a slight advantage in the use of ferric chloride. By the use of the optimum amounts of chemical, it was possible to obtain removals of B.O.D. around 80 to 90 per cent. In working tests on 2,400 gal. tank, the minimum lime for coagulating colloidal matter was 600 p.p.m. The addition of 15 to 20 p.p.m. of ferric chloride proved helpful. The average removal of 5-day B.O.D. was 70 per cent in 1/2 hr., 80 per cent in 1 hr., and 82 per cent in 2 hr. The percentage removal depends on the sucrose content of initial waste, but the sucrose was unaffected. In no case was a stable effluent obtained, although clarification was fairly good.

The addition of ferric chloride was helpful (196, 149), but the advantage derived was not sufficient to offset the cost. Further studies have shown that ferric chloride alone is not satisfactory. From 500 to 550 p.p.m. of lime (as CaO) was required. The coagulation periods ranged from 36 to 77 min., and the settling periods from 106 to 225 p.p.m.

Ferric chloride had little effect on coagulation or removals, even when 80 p.p.m. was used. The ferric chloride was, however, attacked by reducing compounds in the waste. The conclusion was that other means of coagulation than by ferric chloride, such as lime treatment, must be used with the process water.

Owen points out (197) the value of clarification of sugar beet wastes after screening, using 57 to 1230 p.p.m. of lime. Spengler describes (198) several methods of treating beet sugar waste waters with lime, most of which have gone into disuse. A two-stage process in vogue covers fermentation, followed by liming and settling. Bartow states (199) that the diffusion water can be treated with lime and then on sand filters.

Canning.—Holmquist describes (200) the chemical precipitation of canning wastes at Brockport, N. Y., where cherries, peas, green beans, tomatoes, milk, kidney beans and pork and beans were being canned. The monthly average dose of lime used was 6.2 to 6.8 lb. per 1,000 gal. of waste. Copperas was also used in amounts around 0.5 lb. per 1,000 gal. The lime dosage was practically the same as on pea canning wastes in Wisconsin but the optimum dose of copperas in Wisconsin was 3.25 lb. per 1,000 gal. The plant included fine screens (openings 1/2 by 1/16 in.), chemical dry feed apparatus, mixing channel, sedimentation tanks, chlorinator and sludge drying bed. The chlorine was applied to the effluent in amount from 30 to 50 p.p.m., leaving a residual of 0.5 p.p.m. after 15 minutes. Two-hour sedimentation was effective on a continuous basis, or one hour on a fill-and-draw basis. The 5-day B.O.D. was decreased by coagulation and sedimentation from 3,120 to 1,200 p.p.m.

Warrick states (201) that in 1930 there were 18 chemical precipitation plants in Wisconsin treating canning wastes. In 1935, the number had increased to 41. Of these, 6 were of the continuous flow type and 35 were of the fill-and-draw type. He also describes (202) the tests in Wisconsin on pea cannery wastes, indicating that by careful operation and the application of about 3¼ lb. of ferrous sulphate and 7¼ lb. of lime per 1,000 gal. of waste, the 5-day B.O.D. can be reduced approximately 75 per cent. Aeration of the tank effluent will further reduce the oxygen demand.

Warrick notes (203, 204) that the 1928 studies on canning wastes indicated reduction in oxygen demand from 50 to 75 per cent by application of

3¼ lb. copperas and 7¼ lb. lime per 1,000 gal. of pea canning wastes;
2¼ lb. copperas and 6 lb. lime per 1,000 gal. of wax bean waste;
3¼ lb. copperas and 6 lb. lime per 1,000 gal. of corn waste.

A settling period of one hour was sufficient. The daily removal of sludge was essential. The cost of a 3-line pea cannery treatment plant was estimated at $3,500.

Warrick further states (205) that on mixed beet canning wastes the application of 14 lb. lime and 4½ lb. of ferrous sulphate per 1,000 gal. reduces the suspended solids 96 per cent and the 5-day B.O.D. 50 per cent. In treating carrot canning wastes, the use of 7½ lb. lime and 3¼ lb. ferrous sulphate per 1,000 gal. reduced the suspended matter 98 per cent and the 5-day B.O.D. 67 per cent in a 2 hr. settling period on a fill-and-draw basis. The wastes of the cannery were also pumped into the dosing tank of a trickling filter at a neighboring municipal plant.

In a kraut cannery (205) treatment comprising 40-mesh rotary screen followed by chemical precipitation with alum and lime in fill-and-draw tanks, sand filtration using filters equipped to backwash, and chlorination, produced an effluent free from kraut taste and fit for discharge into a small stream flowing through a dairy region.

Coal Washing Water.—The flocculation of water circulating in the washery as well as the effluent is recommended by Raybould (206). The conditioning of coal washing water is discussed in detail.

Creamery and Dairy Products Wastes.—The treatment of milk wastes has been studied by many investigators in different states, in most cases for some state agency or dairy products association, to develop (207) "efficient and economical methods for treatment to secure inoffensive disposal of milk plant wastes." In this work, investigators in Iowa, Michigan, Ohio and Wisconsin have been prominent. Among other procedures, chemical precipitation and chlorination have been tried. Although many investigators agree with Ruf and Warrick that the treatment is best accomplished by trickling filters, comment is found on the use of chemicals and the limitations of the procedure.

Walker concludes (208) that milk wastes may be successfully treated by chemical precipitation with iron sulphate and lime.

Slaughter notes (209) from laboratory experiments that chemical precipitation, using copperas and lime, when properly applied, gives good clarification and materially reduces the oxygen consuming properties of the waste. Eldridge concludes (210) from full size tests, that 4 lb. of copperas per 1,000 gal. is a minimum, added first with lime or caustic soda to give a phenolphthalein alkalinity, will give a good floc formation. The complete removal of the oxygen consuming materials does not seem possible. The effluent is unstable. The sludge does not dry readily. The effluent can be treated on a trickling filter.

Eldridge concludes (211) that chemical precipitation will be limited in application on milk waste treatment. Steel and Zeller believe (212) that sulphuric acid, alum, ferric chloride and ferrous sulphate are of value in the order named for precipitating milk solids. A reduction in B.O.D. of approximately 80 per cent may be expected. Sludge and scum are a troublesome by-product. Wherever possible, a trickling filter rather than chemical methods should be used on dairy wastes.

At Bad Axe, Mich., the city operates a 60,000 gal. per day chemical precipitation plant on milk waste. The effluent is mixed with that of the municipal Imhoff sand filter plant and diluted with well water at low river flows (213).

Minotto describes (214) a treatment of creamery wastes at Phoenix, Arizona, with 60 p.p.m. of chlorine, running the chlorinated waste into furrows for evaporation.

Distillery Wastes.—"Chemical precipitation as applied to distillery refuse is, in principle, a purification system of doubtful efficiency and economy. In practice, so far as known, it has never proven even fairly satisfactory in either particular." So wrote Stabler in 1906 (215) referring also to tests of Wilson (216) on brewery waste with various coagulants.

At a fruit distillery (217), the wastes were reported to have a pH of 3 to 3.5 and a residue on evaporation of 20 to 22 gm. per litre. Neutralization with a 1.2 per cent mixture of lime and water is followed by filtration through gravel and sand. The effluent has a pH of 7 to 7.3 and a residue on evaporation of 8 to 10 gm. per litre.

Dyehouses and Textile Factories.—Garner notes (218) the use of acid as early as 1865 in treating the flow from wool washing establishments in England, using an excess of acid (vitriol) from 500 to 1,000 p.p.m., and then thoroughly mixing by stirring or injecting air. If allowed to stand for 24 to 48 hrs., about 70 per cent of organic matter is removed and 90 per cent of grease. Neutralization of the effluent with lime and precipitation with ferric sulphate has been tried, using large amounts of the precipitants. Although other precipitants were tried, ferric sulphate was most effective, using 5,000 to 10,000 p.p.m. Of the various acids, vitriol has seemed more advantageous.

In handling other waste liquids from dyeing, scouring, bleaching, etc., Garner recommends the trial of chemical precipitation (using lime alone or with alumino-ferric or ferric sulphate), settlement and filtration. As much as 200 p.p.m. of lime and 200 p.p.m. of ferric sulphate have been used.

The Archbutt-Deeley method of water softening was successfully applied (219) to the treatment of dye waters in plants dealing with as much as 500,000 gal. per day. Milk of lime was commonly used, 36 lb. of quicklime being added to 25,000 gal. of waste. This is frequently called the Mather and Platt process, after the name of the firm which commercialized the process. The apparatus was generally installed on a fill-and-draw basis. The retention and re-use of the sludge deposited was a feature of the process (220).

Casselman describes (221) experiments on wastes containing dye and intermediate wastes, investigating filtchar; chlorine; copperas and lime; also alum and lime; strong reducing or strong oxidizing agents; strong

alkali, up to 5 lb. per 1,000 of waste; re-use of waste, shaking with ether up to 5 lb. per 1,000 of waste; dilution, bacterial action.

Hall describes (222) the method of rendering a dyeworks effluent suitable for discharge into a small stream used for fishing. The effluent from prussiate aniline-black dyeing was freed from ferrocyanides by treatment with ferrous sulphate; sodium ferrocyanide was regenerated from the precipitated prussian blue by treatment with sodium hydroxide and sodium carbonate. The treated effluent was added to the main effluent, containing dyes, starches, gums, etc., which was then treated by successive additions of aluminum sulphate and lime, settled and filtered in trickling filters. Settled sludge was treated with lime and filtered.

Michael recommends (223) treatment using sulphuric acid and ferrous sulphate for waste liquors from sulphur black dyeing processes.

Experimental data is discussed (224) by Crisco, White and Baity on coagulation tests on 29 different textile wastes, treated with varying amounts of different reagents, mainly, alum, lime, copperas, calcium chloride, ferric chloride, sulphuric acid or mixtures thereof. In general the combined use of copperas and lime produced the best color removal. Frequently a study of the component wastes is necessary. Sulphur wastes were best clarified by strong acids (H_2SO_4, HNO_3 or HCl).

Food Industry.—McLachlan points (225) out that the chemical treatment of food wastes is frequently unsuitable if secondary biological treatment is to follow. The addition of lime to give optimum pH for coagulation, the flocculation of colloidal and suspended solids by alumino-ferric and soda and the removal of H_2S odors by the addition of ferrous sulphate, ferric sulphate or ferric chloride may be helpful.

Laundry Wastes.—Daniels states that laundry wastes may be clarified by mixing and equalizing the flows so that treatment may proceed at a uniform strength and rate; then correcting alkalinity and adjusting with acid to a pH value of 2.6 for lime or a pH value of 7.0 for alum. Precipitation with lime or alum may follow, with settling. In place of acid, iron sulphate and lime may be used. Alum may also be used instead of lime, together with sulphuric acid. 2.3 cc. concentrated acid and 7 grains of hydrated lime were used per gallon. With iron sulphate, about 30 grains were needed and 112 grains of hydrated lime per gallon.

Boyer notes (226) that laundry wastes are alkaline, with B.O.D. 2 to 5 times that of domestic sewage. For chemical precipitation the pH value of the wastes was adjusted by sulphuric acid to 6.3 to 6.6. Adding 0.4 cc. H_2SO_4 per gal., 240 p.p.m. ferric sulphate (or 160 p.p.m. ferric chloride, or 200 p.p.m. aluminum sulphate), reduced the B.O.D. 85 to 90 per cent. Ferrous sulphate was unsatisfactory. Soda aluminate caused no precipitation. Vigorous mixing for 30 to 40 minutes is recommended.

Mixed Packinghouse Wastes.—In the tests made on Packingtown

sewage by The Sanitary District of Chicago in 1912–1914, a brief study was made of chemical precipitation (227). With chemical precipitation using copperas or alum and lime, or alum alone, during the hours of strong flow (in general 8 A.M. to 11 P.M.) and plain sedimentation during the night and on Sundays and holidays, a reduction in suspended matter of about 80 per cent was secured (Table XIV).

TABLE XIV.—*Chemical Precipitation Removal of Suspended Matter, Mixed Packinghouse and Domestic Sewage, the Sanitary District of Chicago*

Upward Vel. Ft. per Hr.	Detention Period. Hr.	Grains per Gal.		Per Cent Reduction	
		Copperas	Lime	Day †	24-Hour
3.3	3.0	5.5	10.3	76	72
3.3	3.0	4.5	10.2	80	77
3.3	3.0	3.5	9.9	84	79
2.2	2.0	3.3	8.6	78	74
2.2	2.0	3.5	5.1	67	68
2.5	4.0	3.5	5.1	79	70
2.5	4.0	2.4	5.2	82	74
2.5	4.0	5.2	5.5	72	65
1.7	6.0	4.9	6.0	77	—
2.6	4.0	2.4 *	2.8	64	52
2.6	4.0	3.0 *	0.0	73	66
2.6	4.0	1.9 *	2.7	82	76
2.6	4.0	3.2 *	0.0	80	76

* Alum used instead of copperas.

† In general 8 A.M. to 11 P.M., but not on Sundays or holidays.

The apparatus for mixing and applying the chemicals was somewhat crude. In a large installation, at least 3 grains per gal. of copperas and 5 grains of lime would probably be required. Lime is essential to obtain a floc with the copperas. With alum a floc was formed without the addition of lime, but scum formation was excessive. The sludge was more odorous and voluminous than from plain settling.

Halvorson tried ferric chloride on packinghouse waste on a large scale but did not find it satisfactory, because of the long detention period in the settling tank, whereby the ferric chloride sludge became septic, was partially peptized, and went back into solution. A combination of chlorine and ferric chloride might be of value for producing better clarification and a less septic sludge.

Halvorson has also described (228) a chlorination process for the precipitation of colloids, mostly proteins and fats from packinghouse wastes. To the effluent from primary sedimentation chlorine is added at the rate of 1 ton per mil. gal., and the precipitated material removed in

the second clarifier amounts to roughly 2 tons per day per 750,000 gal. of flow. The chlorine is applied in quantity to insure a residual chlorine value of 50 p.p.m. in the precipitation tanks and represents a ratio of 1.5 lb. of chlorine per pound of total nitrogen present in the effluent from the plain settling tank. A pH value of 4 or thereabouts appears to be the optimum condition for the precipitation and maximum nitrogen recovery. It is possible to precipitate 90 per cent of the organic nitrogen content of the wastes if they are fresh. Stale wastes yield as low as 60 per cent nitrogen recovery. In plant practice the average has been 73 per cent recovery of organic nitrogen and 98 per cent removal of suspended solids. The 5-day B.O.D. is reduced from 3,000 to 125–150 p.p.m. The ultimate success of this process depends on the filter pressing and the sale of the sludge. The process is understood to have proved costly at Austin, Minn. because of the amount of chlorine required, and also because of the difficulty of disposing of the sludge. Although chlorine is still in use at Austin, the sludge is dewatered by a vacuum filter and hauled out on farms for use as fertilizer. Reductions of 70 to 85 per cent are reported on the 5-day B.O.D. So far as is known, the Austin plant is the only packinghouse in the United States using the chlorination process.

Halvorson, Cade and Fuller note (229) that precipitation of proteins by adjustment of pH requires a precision in control which is not now practicable (1932). Precipitation was found practicable with ratios of Cl to N of 2 to 10. This required amount of Cl must be added before any precipitation occurs, but the amount of Cl per unit of N is independent of protein concentration.

Eldridge studied (230) coagulation of packinghouse wastes at Grand Rapids in the laboratory, trying acids, lime, sodium hypochlorite, chloride of lime, alum, ferric chloride, ferric sulphate and chlorine. Coagulation required an acid medium at a pH value below 6.0. Coagulation with alum was poor. Ferric chloride and ferric sulphate gave the best results of the coagulants used, with the exception of chlorine. From 256 to 427 p.p.m. of ferric chloride was used, reducing the 5-day B.O.D. from 12.4 to 80 per cent. Tests were made on a full-scale plant (5,000 gal. settling tank) with ferric chloride and chlorine. With 2 gal. of 40 per cent ferric chloride, when cattle were being killed, the 5-day B.O.D. was reduced 84 per cent (from 2,700 to 420 p.p.m.). With 12 to 15 lb. of chlorine, the B.O.D. removal was 92.6 per cent. When hogs were killed, an average B.O.D. of 2,450 was reduced to 1,070 p.p.m. by ferric chloride. An estimate of the cost for maximum results was 3,000 lb. of ferric chloride per mil. gal. at 2¢ per lb., $60.00 per mil. gal., and for chlorine, 2,780 lb. per mil. gal. at 2¢ per lb., $55.60 per mil. gal., 11,900 lb. of B.O.D. were removed per mil. gal. by ferric chloride and 16,540 lb. per mil. gal. by chlorine. Eldridge concluded (231):

(1) Ferric chloride coagulation when applied to slaughter house wastes gives inconsistent results because it does not have the property of completely coagulating blood proteins. This confirms the conclusion of Halvorson (232) that ferric chloride cannot be relied upon to precipitate proteins from all types of packinghouse waste.
(2) Chlorine treatment if properly applied, results in the removal of more than 90 per cent of the B.O.D. and will give consistently good removals.
(3) A small amount of ferric chloride added after the chlorine coagulation aids in settling the floc and concentrating the sludge. Two hours settling then suffices.
(4) Chlorine treatment may be applied successfully at small packing plants as well as at large ones.
(5) Chlorine for such treatment is less costly than ferric chloride, especially when compared on the basis of purification attained per dollar of cost.

Paper Mill Wastes.—In the paper industry, Croft reports (233) that in New Jersey a mill manufacturing chip and newsboard, building and wrapping paper from waste news print is successfully recirculating its waste waters in two separate circuits. A precipitation process is used with a balanced coagulant containing aluminum sulphate and calcium carbonate in the proportion of 55 to 45, in amount about 0.87 lb. per 1,000 gal.

At the paper mill of Bird & Son, Inc. in East Walpole, Mass., chemical precipitation of the machine wastes with sulphate of alumina, and utilization of the sludge in the manufacture of paper has been practiced for many years (234).

Strawboard Wastes.—Sackett concludes (235) that chemical precipitation appears satisfactory for treating strawboard waste but is commercially impracticable from the cost standpoint. Sulphates of iron and alumina were of most value; lime and carbon dioxide alone were of no value. The combination of first saturating with carbon dioxide and then adding milk of lime is effective when properly applied.

Hommon used (236) alum, iron and lime separately and iron and lime combined, in treatment of strawboard wastes, but concluded that the economically settleable solids are removed during a detention period of 2 hours and that the advantage of chemicals used within practical limits is negligible. About 50 per cent of the suspended matter was removed. These conclusions confirm the results obtained by Sackett.

Tannery Wastes.—Hommon concluded (237) that in treating tannery wastes from organic tanning processes the spent-tan liquor may be treated with lime sludge from the de-hairing vats, followed by 24 hours quiescent sedimentation; the supernatant from this treatment may be mixed with the other wastes and the combined wastes treated with ferrous sulphate at the rate of 10 grains per gal.

At the tannery and wool scouring plant of Winslow Bros. and Smith Co. in Norwood, Mass., the combined tannery wastes and an effluent from an acid cracking plant were formerly treated by sedimentation and dilution during the winter and by sedimentation, chemical treatment with

alum and intermittent sand filtration or dilution during the summer and fall, before discharge into the waterway. Coburn notes (238) that pH control was found very advantageous (Table XV) in reducing the cost of treatment and the volume of sludge and increasing the efficiency of treatment. The pH of the wastes is regulated to a range of 5.8 to 6.0 before adding the alum.

TABLE XV.—*Treatment of Tanning Wastes, Winslow Brothers and Smith, Norwood, Mass.*

Item	Average 1914–1922	Average 1923–1925	Reduction Per Cent
pH Control	No	Yes	
Liquid Sludge (gal. per m.g.)	35,820	21,090	41
Dry Solids in Sludge (tons per m.g. wastes)	4.04	3.08	24
Chemicals Used (lb. per m.g.):			
Alum	5,790	2,615	52
Lime	334	145	59
Acid	—	2,803	—

Wool Scouring.—A common method of recovery treatment for wool scouring liquor is known (239) as the "cracking process," in which the liquor is first allowed to settle for a short period, then placed in lead lined tanks and acidified until a breaking up of the liquor or "cracking" is noted. From 20 to 88 per cent of the grease was reported removed at 6 different mills, the Lorraine Mill (Pawtucket, R. I.) showing 78 to 88 per cent.

Chlorination and Lime—Dayton Experience

Chlorine was used with lime by Tatlock at Dayton, Ohio (240) for the purpose of controlling odor. Laboratory examinations during the first season indicated an improvement of the Imhoff influent amounting to 15 per cent or more. This experience was repeated in subsequent determinations. Examination of the Imhoff effluent figures show little, if any, improvement during chlorination periods. It was found, however, that in addition to controlling odor successfully, the use of chlorine smoothed out the plant operation, reduced scum formation on Imhoff tank and improved digestion.

The cost per m.g. per day was given as follows:

Days applied	74
Sewage treated	1,660 m.g.
Total chlorine applied	122,776 lb.
Total lime applied	163,400 lb.
Lb. lime per lb. chlorine	1.31
Lb. chlorine per m.g. sewage	7.4
Lb. lime per m.g. sewage	97
Cu. ft. water per m.g. sewage	380

The cost per mil. gal. per day was as follows:

74 lb. chlorine at $2.115 per cwt.	$1.565
97 lb. lime at $.4925 per cwt.	.478
380 cu. ft. water at $.50 per thousand	.190
Labor, 1 man at $4.00 per day	.179
Total Gross Cost	$2.412
Less labor saved	.22
Net Cost per Day per Mil. Gal.	$2.19

Chlorine and lime have been used at Dayton since the season of 1931, with the same satisfaction in plant operation.

Recent Reports on Large Projects Involving Consideration of Chemical Treatment

Among the recent reports of significance to those interested in the trend of large projects may be mentioned the Eddy-Greeley-Gregory report (164) on the sewage treatment problem of the District of Columbia, the Engineering Commission PWA (D'Esposito-Kutz-Mead-Storey) report (132) on the West-Southwest project of The Sanitary District of Chicago and the Engineering Commission PWA (Bass-Carey-Kutz) report on the Minneapolis-St. Paul project (241).

For the Washington situation, the Eddy-Gregory-Greeley Commission recommended (164) activated sludge treatment, rather than chemical treatment, considering that a high degree of treatment was required for the six warmer months of low river discharge, and that plain sedimentation would suffice during the six cooler months. According to the latest information, at present plans for sedimentation only are being prepared. Digestion of the sludge, dewatering by vacuum filters and removal for agricultural purposes were also indicated.

At Minneapolis-St. Paul, the flow in the Mississippi River is indicated as the controlling factor. Inasmuch as in many years sedimentation alone might suffice, the Bass-Carey-Kutz PWA Board reached (241) the conclusion that sedimentation tanks should be built, equipped to utilize chemicals for supplementary treatment at such infrequent times as the flow conditions demanded.

One of the conditions of the agreement between the Emergency Public Works Administration and The Sanitary District of Chicago was a review of the proposed West-Southwest project by a Board of Engineers selected by the Public Works Administrator. In its report (156) the Board presented some conclusions of interest:

(*a*) The Board that the plan of The Sanitary District of Chicago for treating sewage from the southwest area by the activated sludge process is in accord with the best modern practice.

(*b*) The Board recommended continuing the use of the Imhoff tanks for treating the West Side sewage pending further experiments to determine whether supplementary chemical treatment will so improve the quality of the effluent as to make further treatment unnecessary.

On the other hand, Bowe and Fuller recommended (242) the use of chemical precipitation for the Providence, R. I., Metropolitan District. In this case, the report has been disregarded (243) and Providence is finishing remodelling its old chemical precipitation plant into an activated sludge plant.

Cost of Chemical Treatment

From the reports just mentioned, some data on comparative costs may be drawn.

Metropolitan Sewer Commission, Rhode Island.—In the Engineering Report to the Metropolitan Sewer Commission, Bowe and Fuller presented (242) various projects for the collection and treatment of sewage and industrial wastes now polluting Narragansett Bay and its tributaries. The project covered the Metropolitan Area around Providence and Woonsocket in Rhode Island. One of the alternatives was estimated on the use of chemical precipitation followed by mechanical filters and disinfection with chlorine. The annual cost, as of 1940, for an average sewage flow of 72 m.g.d. was as follows, including operation, maintenance and repairs:

	Total	Per Mil. Gal.
Treatment Works	$504,000	$19.17
Pumping Stations	147,500	5.62
Trunk Sewer System	38,000	1.45
Total	$689,500	$26.24

The operating cost was estimated at:

	Total	Per Mil. Gal.
Chemicals	$302,000	$11.50
Electric Power	38,600	1.47
Labor	71,200	2.70
Fuel and Supplies	42,200	1.60
Maintenance and Repairs	50,000	1.80
Total	$504,000	$19.17

The construction cost of the treatment works with a submerged outfall was estimated at $4,620,000 for 89 m.g.d. capacity, or $52,900 per m.g.d. capacity. If the submerged outfall be deducted (492,000) the cost becomes $4,128,000, or $46,350 per m.g.d. capacity.

The use of ferric chloride with or without lime was indicated with air mixing for 2 min.; flocculation for 15 min.; and settling for 2 hours.

The population served is estimated at 708,000 in 1950, with an additional equivalent population for industry of 580,000.

The estimated costs of operation of the project were as follows:

Date	1940	1950
Flow average m.g.d.	72	93
Treatment Works—		
Chemicals	$302,000	$392,000
Electric Power	38,600	49,500
Labor	71,200	71,400
Fuel and Supplies	42,200	54,100
	$454,000	$567,000
Pumping Station—		
Electric Power	$ 72,000	$ 88,000
Labor	62,500	72,000
Supplies	1,000	1,000
	$135,500	$161,000
Trunk Sewers—		
Labor	$ 29,000	$ 29,000
Tools and Supplies	6,000	6,000
	$ 35,000	$ 35,000
Total Annual Cost of Operation	$624,500	$763,000
Maintenance and Repairs—		
Treatment Works	$ 50,000	$ 66,000
Pumping Stations	12,000	15,000
Trunk Sewer Systems	3,000	5,000
	$ 65,000	$ 86,000

Minneapolis-St. Paul.—The Bass-Carey-Kutz Engineering Board recommended (241) to the Minneapolis-St. Paul Sanitary District the use of plain sedimentation, which should suffice for 90 per cent of the time that the river is not covered by ice. Chemical flocculation prior to sedimentation, with chlorination of the effluent, is recommended for such times as it may be necessary to bring the treatment up to 70 per cent reduction of 5-day B.O.D.

The comparative costs are given, as of 1945, for a total average flow of 134 m.g.d. and a tributary population of 910,000 or 147 g.p.d. per cap. The estimated flow for 1970 is 168 m.g.d. Ferric chloride was assumed (30 p.p.m.) with enough lime for conditioning. The chemical process costs about $1,800,000 less to install and $16,000 less per year to operate than Method No. 2 (Table XVI).

The Sanitary District of Chicago: Southwest Sewage Treatment Works.—The Mead-D'Esposito-Kutz-Storey report (132) compares the cost of activated sludge, sedimentation-trickling filters, sedimentation-preaeration-trickling filters and chemical precipitation-filtration (Table XVII).

The estimated cost of the chemical process was based on the Guggen-

heim process, with a gross charge for chemicals of $10.36 per m.g. and a net cost of $8.56 after sale of ammonia recovered. The Board stated that some supplemental treatment must be provided beyond chemical precipitation, to obtain a degree of purification equal to activated sludge.

TABLE XVI.—*Estimates of Cost for Alternative Methods, Minneapolis–St. Paul Sanitary District*

Methods	First Cost	Annual Costs		Total
		Fixed Charges	M. & O.	
1. Plain Sedimentation plus Chemical Precipitation	$3,241,000	$194,500	$285,200	$479,700
2. Activated Sludge 40 m.g.d.: Plain Sedimentation plus Chemical Precipitation, 94 m.g.d.	5,034,000	302,000	301,800	603,800
3. Activated Sludge, 84 m.g.d. Plain Sedimentation, 50 m.g.d.	5,923,000	355,400	308,900	664,300

TABLE XVII.—*Cost Estimates—400 M.G.D. Southwest Treatment Plant for the Sanitary District of Chicago from Mead-D'Esposito-Kutz-Storey Report*

	Activated Sludge	Sedimentation-Trickling Filter	Sedimentation Pre-aeration-Trickling Filter	Chemical Precipitation-Filtration
Treatment—				
Original Cost per M.G.D.	$26,600[1]	$45,300	$35,700	$18,800[1]
Fixed Charges per M.G.	4.30	6.76	5.33	3.05
Operation per M.G.	4.22[2]	1.84[3]	3.27[3]	10.60
Sub-Total	8.52	8.60	8.60	13.65
Sludge Disposal—				
Original Cost per M.G D.	5,400	3,800	4,400	6,000
Fixed Charges per M.G.	1.01	.71	.81	1.12
Operation per M.G.	3.63	2.54	2.90	3.59
Sub-Total	4.64	3.25	3.71	4.71
Total—				
Original Cost per M.G.D.	32,000	49,100	40,100	24,800
Fixed Charges per M.G.	5.31	7.47	6.14	4.17
Operation per M.G.	7.85	4.38	6.17	14.19
Total	13.16	11.85	12.31	18.36

[1] Does not include royalty.

[2] Includes power cost based upon .5 cu. ft. of air per gallon of sewage.

[3] Includes cost of pumping 10 ft. of additional head.

The use of the zeolite appeared to meet this requirement. "As between the activated sludge process and chemical processes, the cost comparisons clearly support the use of the activated sludge process for the treatment of the Southwest Side sewage."

Recent Installations of Full Scale Chemical Treatment Works

Coney Island Plant (New York City).—Early in July, 1935, a sewage treatment plant was put in operation at Coney Island, New York City, to be operated as a chemical precipitation plant, using lime and ferric sulphate with chlorine in the summer, during the bathing season, and as a plain sedimentation plant in the winter. Gould describes (244) the plant as of a nominal capacity of 35 m.g.d., including four mechanically cleaned circular settling tanks, each 90 feet in diameter (2 hr. detention period at 35 m.g.d.). Dry chemicals are to be handled with pneumatic vacuum pipes to storage tanks, thence to charging hoppers and dry feed apparatus (five machines each with a capacity of 500 lb. per hr. of lime and 1,500 lb. per hr. of ferric sulphate or copperas). Four chlorine machines are provided, each with a maximum capacity of 2,000 lb. per 24 hr. Mechanical flocculators are provided, preceded by rapid mixing devices (flocculation period 11.5 min.). Digestion tanks (8 in number) have a total sludge capacity of 478,000 cu. ft. Gas-holder types of cover give a total gas storage capacity of about 200,000 cu. ft. At present one vacuum filter (570 sq. ft. area) will be installed. The estimated cost for the present installation is $1,823,000, including plant outfall, wharf, bulkheads, fill and force main, which total $666,000.

North Shore Sanitary District.—The Waukegan plant of the North Shore Sanitary District, Ill., now under construction, is designed for a population of 50,000 with a sewage flow of 10.0 m.g.d. The principal structures include a sewage pumping station, mechanical grit chamber, grease removal tanks, chemical building and application devices, flocculation tanks, settling tank of the two story type, chlorination equipment and contact tank, sludge drying beds and outfall into Lake Michigan.

Following the grit and grease removal tanks, hydrated lime is to be applied by dry feed machines and ferric chloride in dilute solution. Two dry feed machines for lime are provided, each with a capacity range between 30 and 300 lbs. per hour. Two solution feed devices are provided, each with a capacity range between 0.10 and 0.85 gallons per minute of 40 per cent solution with dilution to a 2 to 10 per cent solution before application. The two flocculation tanks are provided with both air and mechanical agitation and have a displacement period of 15 minutes at 10.0 m.g.d.

The Imhoff tanks are in four units, each about 75 ft. square. Provisions are included for mechanical prevention of deposition in conduits

and for reversal of flow. The displacement period is 2.0 hours with a flow of 10.0 m.g.d. The sludge volume is 310,000 cu. ft. or 6.2 cu. ft. per capita design basis.

Chlorination is provided for the settling tank effluent, with 15 minutes displacement in the contact tank before discharge into Lake Michigan.

Chemical treatment and chlorination is planned for use only during the summer recreation season. Consequently, sludge handling, digestion and sludge drying capacities have been computed on a 5-months basis.

Seasonal Use of Chemical Treatment

An inspection of the various reports on proposed work and on the plants in operation or under construction or proposed (Tables XXI, XXII, XXIII) indicates that the seasonal use of chemical treatment has appealed to many engineers in dealing with a problem of pollution where adequate dilution is available to supplement sedimentation for the greater portion of the year. Consideration was given to this application for the District of Columbia, but owing to the lengthy period required for such treatment and consequent cost, activated sludge was recommended. However, the plant at present is being constructed as a settling plant with separate sludge digestion. At Minneapolis-St. Paul, the period of supplementary treatment is relatively short and may be infrequent. Chemical treatment has been recommended. At Grand Rapids, Mich., following the experiments, plans are being prepared for seasonal chemical treatment supplementing sedimentation, using ferric chloride. A seasonal use of chemicals is also in effect at Perth Amboy, Shades Valley and Owosso.

In other localities where bathing beaches are affected by the discharge of effluent from a sedimentation plant, the seasonal use during the bathing season of chemicals for primary coagulation, with final chlorination, has been selected as a suitable means of producing a better effluent with a lower bacterial content than sedimentation alone would provide. Such applications are found at Waukegan, Ill. (North Shore Sanitary District) and Coney Island (New York City).

Adoption of Policy by State Board of Health

On Chemical Precipitation for Sewage Treatment.—At least one state has adopted a specific policy with reference to chemical precipitation.

On April 2, 1934, the New Jersey State Board of Health adopted (245) a policy relating to the use of chemical precipitation for sewage treatment, together with rules and regulations for the preparation and submission of designs for sewage treatment works containing chemical precipitation devices, as follows:

Policy of New Jersey State Board of Health.—The method of sewage treatment, chemical precipitation, shall be considered as a degree of treatment intermediate between what are commonly known as sedimentation, and sedimentation and oxidation.

At sewage treatment works which discharge their effluents into intra-state waters later used for public potable purposes, the method of chemical precipitation shall be supplemented by methods of oxidation and chlorination; at sewage treatment works which will discharge their effluents into certain areas of interstate and intra-state waters, the method of chemical precipitation shall be supplemented by method (s) of oxidation and/or chlorination.

Sewage treatment works using the method of chemical precipitation, or using the method of chemical precipitation along with other methods of treatment, shall be approved only when the applicant (owner, and in case of a municipality or other governmental authority, the elective official or authorized body), by formal action advises the Department of Health of the State of New Jersey that the proposed works will be under skilled technical supervision at all times and that the works will be adequately manned twenty-four hours per day.

These rules and regulations for the design of sewage treatment works containing chemical precipitation devices are minimum rules and regulations and are subject to changes and additions.

Modern British Practice

In 1932, a summary of 146 sewage works in Great Britain indicated (246) that of 45 using chemical precipitation, there was the following distribution by coagulants:

Chemicals	No. of Plants
Acid	2
Alumino ferric	15
Alumino ferric plus iron sulphate	1
Alumina sulphate	1
Alumina sulphate plus charcoal	1
Ferric sulphate	3
Iron Salts (natural)	1
Lime	9
Lime plus alumino ferric	5
alumino ferric plus clay	1
alumina sulphate	2
copperas	2
ferric sulphate	2

Of the 45 plants using chemical precipitation, the distribution of sludge handling was as follows:

Type of Sludge Handling	No. of Plants
Digestion	1
Digestion and pressing	1
Digestion, drying beds and pressing	1
Drying beds	7
Irrigated	1
Lagoons	5
Lagoons and drying beds	5
Land	5
Pressing	12
Pressing and drying	1
Pressing and lagoons	1
Out to sea	2
Trenching	3

Dr. H. T. Calvert (Chief Inspector, Ministry of Health) estimates the number of sewage treatment works in Great Britain at about 3,000, of which probably about 100 are using chemicals. Chemical precipitation is used either to reduce the load on a land area or on biological beds. In Great Britain, chemical precipitation does not appear to be favored as a final method of disposal, nor is any difference in treatment made as between winter and summer. At London, from 1890 to 1910, lime and copperas were employed. The copperas was first dropped and then the lime. Recently, the use of chemicals has, again been suggested during the hot summer months. Nevertheless, the London County Council is about to embark on an expenditure of £ 600,000 for installing an activated sludge plant to deal with a portion of the sewage.

Germany—Present Situation

Statistics show (247) that in Germany, with a population of 65,000,000, the sewage of only 26,000,000 people receives treatment of some sort (Table XVIII). Of these, the sewage of only 156,100 people receives

TABLE XVIII.—*Sewerage Facilities in Germany*

	Cities	Population
Sewers and Treatment Works—		
Screening Plants	55	7,000,000
Other Types of Treatment	585	19,000,000
Total Treated	640	26,000,000
Sewers but No Treatment		6,500,000
Rural or Small Towns with Open Channels		32,500,000
Total		65,000,000

chemical treatment. Out of 646 cities having treatment works, only 10 use chemical treatment. The cities are listed in Table XIX. The information would indicate that none of these plants are of recent origin, practically all having been built prior to 1908, so far as can be ascertained.

TABLE XIX.—*Sewage Treatment Works in Germany Using Chemical Treatment*

City	Population	Remarks
1. Baden-Baden	16,000	Built in 1897. Lime and $MgSO_4$.
2. Burgstadt	8,900	Final treatment in contact bed.
3. Elbing	63,000	Ground peat, 1908–1919. Since 1919, plain sedimentation.
4. Langenbielau	16,000	Built 1908. Lime and alum.
5. Munden	11,200	No information.
6. Neisse	9,000	Alum. Total population, 34,400.
7. Neustadt (Silesia)	20,000	Built 1896. Lime.
8. Potsdam	75,000	Built 1898. Ground peat and alum.
Total	219,000	
Omitting Elbing	156,100	

Chemical Precipitation in United States

From a careful survey of all the sewage treatment works in the United States, the distribution by types of treatment was ascertained (248) in 1934 for the 3,165 incorporated cities (1930 census) over 2,500 (Table XX). This survey indicated 1,228 cities with plants in operation, 42

TABLE XX.—*United States. Sewage Treatment Works in Cities Over 2,500. Distribution by Types of Treatment in 1934*

Type of Treatment	In Operation	Under Construction	Under Design
Fine Screens	20		
Sedimentation	36		5
Sedimentation and Separate Digestion	84	12	23
Septic Tank	252		
Imhoff Tank	245	4	5
Aeration Sedimentation			
Direct Oxidation	1		
Chemical Precipitation	4	1	5
Contact Beds	55		
Intermittent Sand Filters	144		1
Trickling Filters	318	15	53
Activated Sludge	69	10	31
	1,228	42	123

with plants under construction and 122 under design or proposed. The plants included therein on chemical precipitation did not include the seasonal users of chemicals. During 1934, there was more capacity under construction or contemplated for the activated sludge process than for any other. Imhoff tanks to serve nearly 500,000 population were under construction and planned for additional population. Separate digestion plants were also built and planned, but in somewhat less degree. Several projects were started on chemical precipitation on a throughout-the-year basis, but the greatest interest seems to have shifted (as measured by population) to seasonal application.

TABLE XXI.—*Sewage Treatment Works in the United States. Chemical Precipitation Plants. Plants in Operation—1935*

State	City	Population 1930	Remarks
Alabama	Jefferson County		Shades Valley plant. Seasonal use of chemicals. 2 m.g.d. capacity.
California	Signal Hill	2,932	25,000 gal. per day. Alum and lime.
Colorado	Boulder	11,223	Ferrous sulphate.
Michigan	Bad Axe	2,332	Lime and ferrous sulphate treatment prior to sand filtration.
	Benton Harbor	800	House of David. Putnam process, followed by sand filtration.
	Dearborn	50,358	Plant serves population of about 12,000. Laughlin process.
Nebraska	York	5,712	Scott-Darcey process, 0.7 m.g.d.
New Jersey	Camden County		Iron salts and chlorine.
	Essex Fells	1,115	Scott-Darcey process.
	Lakewood		Iron salts and chlorine.
	Perth Amboy	43,516	Laughlin process. Chlorine. Seasonal use of chemicals.
	Phillipsburg	19,255	Lime only.
	Plainfield	34,422	Applied to peak loads, raw sewage; and to trickling filter effluent. Chlorinated copperas.
	Verona	7,161	Chemical precipitation, trickling filters, chlorination. Uses chlorinated copperas.
New York	New York City	300,000	Coney Island plant, 35 m.g.d. Seasonal use of lime, ferric sulphate and chlorine.
	Rockville Center	13,718	Bio-aeration, effluent vacuum filtered.

TABLE XXI.—*Continued*

State	City	Population 1930	Remarks
North Carolina	Gastonia	17,903	Used for color removal.
	High Point	36,745	
	Winston-Salem	75,274	Landreth electrolytic process.
Ohio	Ashland	11,141	Lewis-Travers. Marl, hydrated lime and copperas.
	Orrville	4,427	Ferric chloride and lime, prior to sand filtration.
Oklahoma	Cordell	2,936	Scott-Darcey.
	Duncan	8,363	Scott-Darcey.
	El Reno	9,384	Scott-Darcey.
	Enid	26,399	Scott-Darcey.
	Fairview	1,887	Scott-Darcey.
	Oklahoma City	185,398	Scott-Darcey (2 plants). Lime at one plant.
	Perry	4,206	Scott-Darcey. Lime.
	Stillwater	7,016	Scott-Darcey.
	Temple	1,182	Scott-Darcey.
South Dakota	Sioux Falls	33,362	Trickling filter plant. Additional Activated Sludge unit, chemical precipitation tank.
Wisconsin	Gillette	1,076	Installed 1927. Sludge pumped direct to sludge beds. Lime.
	New Holstein	1,274	Installed 1925. Lime. 2 hr. detention.
	Waupun	4,768	Installed 1927. Lime and ferrous sulphate.
	Westby	1,368	Installed 1927. Equipped for lime and alum feed. Sludge pumped to digestor.

The *Engineering News-Record* survey (249) indicates a total of 3,471 communities served by 3,697 sewage treatment works in the United States. So far as can be identified, that survey indicates only 16 sewage works using chemical treatment for coagulation.

The canvass made by the Committee lists the sewage treatment works using chemical precipitation in the United States (Tables XXI, XXII, XXIII and XXIV), separating the plants in operation (total 35) under construction (total 9) and contemplated (total 18), and also indicating where experimental work only is now being conducted. The tabulation omits all purely industrial applications, as in canneries, textile industry or otherwise. In the tables are indicated the plants which have seasonal application of chemicals as distinguished from those where chemicals are applied throughout the year.

TABLE XXII.—*Sewage Treatment Works in the United States. Chemical Precipitation Plants. Plants under Construction—1935*

State	City	Population, 1930	Remarks
Illinois	Waukegan	33,499	Seasonal use of chemicals contemplated. (Imhoff tanks)
Iowa	Cedar Rapids (Packing House)		Flow of approx. 1.2 m.g.d.
Michigan	Owosso	14,496	Use of ferric chloride during low water, possibly seasonal.
	Rockford	1,613	No data on chemical to be used.
North Carolina	Spindale		Lime and iron precipitation; rapid sand filters. 0.6 m.g.d.
Oklahoma	Durant	7,463	Scott-Darcey.
Texas	El Paso	102,421	Remodeling existing settling and separate digestion plant. Provision for ferric chloride as coagulant and for chlorine on effluent when needed.
	Paris	15,649	Similar to Shades Valley plant.
Virginia	Arlington Co.	26,615	Clarification and chlorination. Provision for occasional use of chemicals.

Conclusions

The chemical treatment of sewage includes a wide range of effort. From the data cited herein it would appear;

1. Chemical treatment usually accomplishes a degree of treatment between plain sedimentation and biological processes.

2. By the addition of a zeolite filter following precipitation with generous amounts of chemical, the Guggenheim process substantially equalled an activated sludge effluent.

3. The seasonal or occasional use of chemicals is attracting favorable notice in situations where sedimentation alone may suffice for the greater part of the year or for many years out of a cycle.

4. The use of chemicals as a preparatory treatment in addition to sedimentation ahead of biological filters is practised in many situations, and prolongs the useful life of existing plants, otherwise overloaded.

5. Of the various processes for chemical treatment of sewage considered in the United States, the use of iron salts, particularly ferric chloride or ferric sulphate seems most favored.

6. The manufacture of iron salts from scrap iron or tin cans with chlorine has been favored in many situations for reasons of economy.

7. The use of iron salts, particularly ferric chloride, for sludge conditioning prior to vacuum filtration has been generally adopted where practicable.

TABLE XXIII.—*Sewage Treatment Works in the United States. Chemical Precipitation Plants. Proposed in 1935*

State	City	Population 1930	Remarks
Alabama	Jefferson County		Rumored that chemicals may be used at Ensley and Tarrant City plants.
California	San Diego		0.12 m.g.d. (part of city) Stevenson process.
	San Luis Obispo	8,276	1 m.g.d. (part of city) Stevenson process.
Colorado	Colorado Springs		10 m.g.d. PWA allotment.
Connecticut	New Britain	70,000	Guggenheim, aeration. 9 m.g.d.
Illinois	Danville	40,000	Seasonal use of chemicals.
Kentucky	Providence		3 m.g.d. Application made to PWA.
Michigan	Mt. Clemens	13,497	Application made to PWA.
	Grand Rapids	168,592	Financing under way for coagulation and chlorination at low water periods.
Minnesota	St. Paul-Mpls.	745,971	Seasonal use contemplated.
Missouri	Kahoka	1,507	Anhydrous ferric chloride.
	Neosho	4,485	Scott-Darcey.
New Jersey	New Brunswick	34,555	Seasonal chemical precipitation.
	Westwood, Borough of	4,861	Iron salts proposed.
New York	Elmira	47,397	No data on chemicals to be used.
	Freeport	15,467	Converting sedimentation to chemical precipitation.
Virginia	Virginia Beach	6,000–15,000	Sedimentation plus trickling filter, chemical precipitation in summer to reduce load on filter.
Wisconsin	Appleton	30,000	Seasonal. Paper wastes. Total flow, 10 m.g.d.

TABLE XXIV.—*Experimental Work, Chemical Precipitation of Sewage*

State	City	Population, 1930	Remarks
Georgia	Atlanta		Precipitation with chlorinated copperas prior to trickling filters. Control of pH with CO_2.
Illinois	Aurora	46,589	Experimental, 1934, with alum, ferric chloride, and ferrous sulphate.
New York	Ithaca	20,708	Experiments with activated carbon (separate digestion plant).
	Liberty	3,427	1 m.g.d. experimental work. Iron salts, lime and chlorine.
	Newark	7,649	Experiments with activated carbon on sludge conditioning.

8. The comparison of chemical treatment of sewage with other procedures should be studied carefully from the standpoint of adequacy, performance, and cost.

9. The use of chemical treatment in handling industrial wastes appears to have a definite place, where performance and cost justify the procedure as compared with other methods.

The Committee presents this report as a summary. If errors are found or additional data are available, the Committee would welcome the information at an early date, if sent to the Chairman.

Appendix A

CHEMICAL TREATMENT OF SEWAGE

Selected U. S. Patents Relating Thereto

Number	Date	Patentee	
138,250	4–29–1873	Hille	Treatment with lime, zinc chloride, magnesium chloride; settling, filtration. Treatment with lime and after settling, with carbonic acid to precipitate any excess of lime.
352,894	11–16–1886	Slater	Making muriate of alumina for precipitant.
495,834	4–18–1893	Powers	Means for chemical treatment; mentions perchloride of iron, lime and chlorine gas for disinfection.
505,182	9–19–1893	Adeney and Parry	Treating sewage with manganate of soda and nitrate of soda. Also recovery of manganese.
622,401	4– 4–1899	Spence	Use of mixture of aluminic sulphate, ferric sulphate and sulphuric acid sufficient to neutralize alkalinity.
671,353	4– 2–1901	Reeves	Mixing lime water with sewage, treating supernatent with manganate of soda and sulphuric acid.
730,588	6– 9–1903	Vial	General precipitation by reagents. Mentions sulphuric acid.
869,272	10–27–1907	Spence, Spence, Ockel	Treating sludge with mineral acid and not pressing to recover fat.
966,025	8– 2–1910	Lautzenhiser, Chandler	Electrolytic apparatus.
1,015,302	1–23–1912	Dickson	Use of brewers yeast, etc.
1,025,622	5– 7–1912	Grossman	Recovery of grease from sludge by acid treatment, heat and distillation (H_2SO_4).
1,122,474	12–29–1914	Butterfield	Treatment of sludge.
1,134,280	4– 6–1915	Miles	Use of inorganic acid for precipitant of sewage; mentions H_2SO_4; claims use of sulphurous acid or SO_2.
1,139,778	5–18–1915	Landreth	Electro-chemical process. Use of alkali (lime) and electric current. 70 claims.
1,146,942	7–20–1915	Landreth	Electrolytic.
1,166,373	12–28–1915	Irwin	Chemical precipitation (basic or acid phosphate); mixing sludge with a ferment temperature raised to 90° F., flotation of sludge.
1,194,000	1– 9–1917	Noble	Use of carbonate of lime and hypochlorite of lime.
1,229,305	6–12–1917	Menzies	Removal of excess Cl following chlorination; use of SO_2 and manganese permutit.

Appendix A.—*Continued*

Number	Date	Patentee	
1,263,532	4–23–1918	Cummings	Use of CO_2 on waters or sewage containing lime.
1,284,441	11–12–1918	Phillips	Treatment of sludge with phosphoric acid.
1,284,442	11–12–1918	Phillips	Treatment of sludge by mineral acid, neutralizing by phosphate rock (H_2SO_4 suggested).
1,307,686	6–24–1919	Linden	Apparatus for separation of solids.
1,325,787	12–23–1919	Grossmann	Use of acid (H_2SO_4 or HCl) for separating solids from sludge.
1,364,387	1– 4–1921	Landreth	Apparatus.
1,392,211	9–27–1921	Peck	Methods of operation of activated sludge to fix atmospheric nitrogen. Favored use of iron or its salts. Note: Did not work.
1,392,212	9–27–1921	Peck	Stimulation of biological growths; prefers iron salts.
1,392,213	9–27–1921	Peck	As above.
1,392,214	9–27–1921	Peck	Apparatus.
1,440,253	12–26–1922	Travers	Mixture of marl clay, hydrated lime, ferrous sulphate, 20 to 200 grains per gal.
1,455,435	5–15–1923	Fairbrother, Renshaw	Use of oxazine dyes, meldola blue and auramine O to control bulking in activated sludge.
1,507,121	9– 2–1924	Landreth	Methods of electrolysis.
1,511,418	10–14–1924	Maclachlan	Use of SO_2 in dehydrating sewage or activated sludge.
1,543,939	6–30–1925	Machlachlan	Treating sludge with a traveling belt and squeezing rollers. Use of SO_2.
1,617,014	2– 8–1927	Derleth	Use of diatomaceous earth for coagulation or prior to aeration.
1,658,974	2–14–1928	Laporte, Dallyn, Manuel	Use of a floc of aluminum and iron salts (or hydrate) to absorb, coagulate and precipitate. Prior agitation with air.
1,672,584	6– 5–1928	Travers	Use of waste dust from cement manufacture, with or without lime, ferrous sulphate or other precipitants.
1,672,585	6– 5–1928	Travers	Use of waste material precipitated in manufacture of chlorine, chloride of lime and caustic soda; plus lime or ferrous sulphate or other precipitants.
1,672,587	6– 5–1928	Travers	Mix contains calcium hydroxide, electrolyte producing material and coagulant (such as calcium hydroxide, calcium sulphate, ferrous sulphate). Claims various methods.
1,715,877	6– 4–1929	Travers	Use of $Ca(OH)_2$ and $CaCO_3$ in treating acid wastes.
1,734,011	10–29–1929	Harrison	Selective agitation, introduction of enzyme and bacteriophage, etc.

Appendix A.—*Continued*

Number	Date	Patentee	
1,747,803	2–18–1930	Travers	Process and apparatus.
1,797,157	3–17–1931	Rudolfs	Use of sodium aluminate to aid digestion of sludge.
1,797,879	3–24–1931	Rudolfs	Treating sewage with iron salts in amount 3.5 to 50 p.p.m. (refers to ferric chloride).
1,799,444	4– 7–1931	Sperr, Jr.	Aeration of sewage with metal salt present whose sulphide is insoluble, with foaming at surface. Mentions alkali, ferric hydrate, iron oxide, nickel sulphide.
1,877,623	9–13–1932	Laughlin	Adds hydrated cellulose as a precipitant. Recommends adding ferric chloride or lime, or both.
1,886,267	4–18–1933	Gleason, Loonam	Use of ferric sulphate, followed by lime; recovery of iron; treatment of liquid by zeolite; recovery of ammonia.
1,904,246	4–18–1933	Ornstein	Clarification of sewage by sedimentation prior to chemical treatment with coagulant; digestion of chemical sludge.
1,915,240	6–20–1933	Putnam	Use of carbon compound including ferric oxide, secured from previously treated sludge; also lime, ferric chloride, ferric hydroxide.
1,917,516	7–11–1933	Gilliland	Treating sludge. Obtained with yeast precipitation.
1,928,163	9–26–1933	Barnard	Process and apparatus for use with Lewis process.
1,930,448	10–10–1933	Roundy, Amos	Pentachloride in connection with ferric chloride.
1,935,963	11–21–1933	Urbain	Removal of carboxylic acids.
1,935,964	11–21–1933	Urbain	
1,937,481	11–28–1933	Raisch, Wright	Filtering sewage through a mat of paper pulp and sewage solids on a vacuum filter.
1,955,064	4–14–1934	Hawley	Separation of solids by contact with mineral oil.
1,955,065	4–17–1934	Hawley	Use of oil to mix with pollution liquid-separation.
1,956,420	4–24–1934	Gleason, Loonam	Use of ferric sulphate and lime.
1,963,581	6–19–1934	Heukelekian	Adding cultures of thermophilic bacteria to sludge and heat from 50° to 70° C.
1,964,444	6–26–1934	Urbain	
1,965,268	7– 3–1934	Thomsen	Reactivation of lime.
1,968,114	7–31–1934	Windecker	Chlorine and lime; settle, chlorinate effluent and sludge.
1,968,724	7–31–1934	Urbain	
1,973,168	9–11–1934	Henderson, Kennedy	Lime and hypochlorite.
1,997,302	4– 9–1935	Koller, Miller	Alkali and oxygen containing substance and copper sulphate or other metallic salt.

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EXPERIENCES WITH SEWAGE AND SLUDGE PUMPING EQUIPMENT

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Centrifugal sewage pumping equipment may be grouped into four general classes:

1. Vertical submerged pumps, similar in construction to the common sump pump.
2. Vertical non-submerged pumps.
3. Horizontal pumps located in a dry well below the level of the sewage.
4. Horizontal self-priming pumps located above the level of the sewage.

Vertical Submerged Pumps

Where the wet well is shallow and the pump reasonably small, vertical submerged construction, as used on a typical sump pump, generally provides the least expensive installation and is most likely to be free from installation difficulties. The saving in cost is not in the pumping equipment proper, but in cost of the building. No dry well is required, excavation costs are lower, and as only a vertical motor and cover plate is mounted on the motor room floor, the floor space required is relatively small. A small building can be used, but care should be taken to provide enough head room so that the entire unit may be lifted out of the wet well for repairs. A heavy roof beam and chain hoist should be installed. Installation difficulties are negligible, as the entire unit is assembled by the pump manufacturer, and needs only to be set in place by the contractor.

These advantages are offset by maintenance difficulties. The pump is submerged in sewage, cannot be serviced or inspected, and if any mechanical difficulties develop, the discharge pipe must be disconnected and the entire unit hoisted out of the well.

Bearings and shaft are enclosed in pipe, and if repairs are needed, the entire unit must be knocked down. Bearings are of special design, and must be procured from the pump manufacturer, and the pump is out of service until the parts can be procured. Machinery that has been submerged in sewage for months or years is not pleasant to work upon.

On one plant, four small sludge pumps of the vertical submerged type were furnished. These were installed as two pumping units, each pump provided with a stand-by unit. Each of the four pumps was installed in a separate wet well, with no cross-connections between wet wells. The pumps handle raw sludge from settling tanks, and are located adjacent

to the settling tanks. The motors are water-proof type, in shallow concrete pits, with steel covers. As there is no pump house, no provisions are possible for a hoist, and the assembled units cannot be lifted out of the wells. With this arrangement, the sludge can be diverted to either of two wells and handled by either of two pumps. If one of the pumps goes out of order while its wet well is full of sludge, this well cannot be emptied by the stand-by unit. In order to gain access to the pump that needs repairs, the sludge must be bailed out of the well, and the repairs must be made in the wet well, which cannot readily be cleaned, and which provides a most uninviting atmosphere, occasioned by the raw sludge handled. Repairs under these conditions are costly and difficult.

When submerged pumps must be used, it is always advisable to provide a stand-by unit. This unit should be located in the same wet well as the main pumping unit, or connected with it. The discharge pipes should be brought out through the cover plate and convenient flanges provided so this pipe can be disconnected. A pump house and hoist, whereby the pump can be raised out of the wet well, will make repairs and access to the pump more practical.

Sump pump construction should be used only on small pumps, as the entire weight of the unit must be supported from the cover plate at the motor floor. On larger units, or where the wet well is unusually deep, more rigid construction can be attained by supporting the pump on a pump base, firmly anchored to the floor of the wet well. With this construction, the upper side plate of the pump is made removable, to permit raising the shaft, impeller and all rotating elements without breaking suction or discharge piping.

A submerged pump is an excellent unit while it works, but it cannot be inspected; repairs cannot be anticipated; it is likely to fail when most needed; must be removed from the well, knocked down and re-assembled even for minor bearing trouble, and is likely to be out of service for some time whenever repairs are made.

Vertical Non-Submerged Pumps

Vertical non-submerged pumps are most commonly used in modern sewage pumping stations. On units of four-inch discharge and larger, the pump unit generally does not cost appreciably more than a pump of the same size, with submerged construction. The cost of a non-submerged installation will be greater, due to the dry well required for the pump, and higher erection costs. The dry well must be large enough to allow ready access to the pump and bearings and deep enough to assure a primed pump under all normal operating conditions.

Skilled mechanics, preferably with experience in the installation of vertical pumping equipment, are essential where the installation of ver-

tical non-submerged pumps is involved. These units cannot be fully assembled by the pump manufacturer. The pump is generally shipped as one unit, and intermediate shafting, guide bearings, thrust bearings, motor stand, and motor must be mounted in the field.

The pump should have a large foundation, extending completely around the unit, to provide a rugged support in all directions. After the exact location in the dry well is determined, the pump should be levelled up with utmost accuracy, bolted, and grouted into place. This operation can be expedited if suitable levelling pads, properly machined, are provided on the pump shell, to permit the erector to check his job with a good level. These pads are also an aid to the engineer in checking the erection job, and a convenience to the operator, as he can at any time confirm, or dispel, a suspicion that his equipment has shifted or settled.

Special emphasis is placed on the setting, and leveling of the pump proper, for misalignment has in the past been the greatest single source of trouble on vertical pumps erected in the field.

The intermediate shafting, connecting the pump to the motor, must be aligned with the pump shaft. If the pump shaft is out of vertical alignment only slightly, this error is magnified, due to the length of the connecting shafting, and the error at the motor is bound to be greater and often serious. Misalignment is at times caused by stresses set up by suction and discharge piping. All pipe lines should be supported independently of the pump shell. If flanged connections are used, the flanges of pump and pipe must match accurately. A perfectly aligned job can be ruined if the flanges do not match perfectly, and the erector attempts to pull them tight by means of the bolts. A pump shell is not designed to carry the weight of the piping, nor to withstand external stresses incident to the making of a forced fit between the pump and piping.

The connection between the pump suction and wet well is usually short. The suction line is generally anchored in the wall separating the wet and dry wells. To permit some leeway in making the suction connection to the pump, a bell-end is recommended for the elbow on the pump suction. The bell-and-spigot connection does not require a perfect fit, allows some leeway, and avoids any stress on the pumping unit. Hence, a good aligning job will not be ruined, as it might well be if the flanges on the suction pipe fail to match perfectly.

Vibration is another source of trouble, and on a properly designed unit is most frequently due to misalignment. Such troubles can be avoided only by correct erection of the equipment. Unfortunately, the low bidder is not always the most competent and experienced erector. Difficulties due to vibration or misalignment rarely occur if the erection of all mechanical equipment is awarded as a separate contract to a qualified mechanical contractor.

Faulty supports for guide and thrust bearings for the intermediate shafting are likely to cause excessive vibration and high maintenance costs. An eight or ten-inch "H" beam is heavier and more rigid than a channel, and generally more satisfactory. The top of the H-beam can be filled with concrete, thereby adding to the mass and rigidity of the bearing support. Each bearing should have an independent supporting beam, this member to be as short as practical.

On one of the older plants, the bearings for the two pumps were supported by one long channel. The length of the channel permitted excessive deflection. When vibration occurred in one pumping unit, it was transmitted through the channel to the second. As a result, the bearings on both pumps were subjected to abuse, and required frequent attention and repair. By installing a short, rigid H-beam support for each bearing, and by properly aligning each pumping unit, this trouble has been eliminated.

Care must be exercised in selecting the number and location of guide and thrust bearings to support and steady the intermediate or connecting shaft.

It is recommended that the weight of this shafting be carried by a liberally sized thrust bearing independent of the motor. This arrangement permits the use of a flexible coupling between the connecting shaft and the motor. While a flexible coupling is no excuse for poor alignment, it does compensate for slight inaccuracy in alignment, and permits the selection of a thrust bearing with a very liberal overload capacity. Where the weight of the shafting is carried by the motor thrust bearing, the motor manufacturers' standard thrust bearing must be used. A solid, or rigid, coupling must be installed between the motor and connecting shafts. With this arrangement, the motor bearings, and guide bearings for the connecting shaft must be in absolutely perfect alignment. Any vibration in the connecting shafting is transmitted to the motor bearings, resulting in excessive shock loads, which shorten the life of the bearings. In the event of bearing failure, the replacing bearing must be procured from the motor manufacturer.

The thrust bearing supporting the shaft should be located within 18 inches of the upper end of the shaft. The lower end of the shaft, near the pump, should be guided by a guide bearing, also located within 18 inches of the end of the shaft. The objective in locating these bearings near the extremities of the shaft is to avoid a whipping action which may be set up if the flexible couplings are not absolutely true.

We now have the support for both ends of the connecting shaft. Unless oversize shafting is used, additional guide bearings should be installed to furnish regularly spaced supports for the shafting on not less than 7-foot centers.

A solid, or flanged, coupling should be furnished between each set of guide bearings to permit handling of the shaft in sections during assembly.

As sewage and sludge pumps must handle solids, both pump and connecting shafts are subjected to shock loads not encountered on a clear water installation. To take care of these loads, the diameter of shafts and bearings should be very liberal in size. Two-inch shafts and bearings of a four-inch discharge pump, two-and-a-half-inch shaft and bearings, on a six-inch pump, and proportionately larger shafts and bearings on larger pumps, have been found satisfactory.

It is possible that a pump designer can mathematically prove smaller diameter shafts to be ample. There is, however, very little difference in cost between two-inch and one-and-one-half-inch shafting and bearings. The oversize shafts and bearings provide an added safety factor. The replacement of a single defective bearing is likely to involve the disassembly and realignment of the entire unit, a job which requires the services of skilled mechanics and naturally a considerable repair bill. By demanding oversize shaft and bearings, you add slightly to the initial cost of the unit, but it is a rare instance, indeed, where this added cost is not returned many times over, in decreased maintenance bills and in more dependable operation.

In some stations an intermediate floor or gallery is installed between the bottom of the dry well and the motor floor. With this design, the distance between the guide bearings cannot be maintained at seven feet or less without a guide bearing and H-beam support between the motor floor and the gallery. A series of H-beam supports less than eight feet above the gallery floor would limit the head room available and tend to limit the usefulness of the gallery floor space. The more satisfactory arrangement is to locate a bearing at each floor, avoiding H-beam supports and limited head room. A distance between bearings exceeding ten feet can be used if the diameter of the shaft between bearings is increased sufficiently to avoid excessive deflection. In one instance, two-and-a-half-inch bearings on ten-foot centers were successfully used by increasing the shaft diameter between bearings from two-and-a-half to four-and-a-half inches. Here again it must be admitted that the diameter of the shafting between bearings far exceeds the diameter theoretically required, but the installation looks rugged, and has required no maintenance expenditure due to vibration or excessive deflection.

Ball bearings are now used on most vertical pumps. By selecting a bearing designed for grease lubrication, the throwing of oil by the pump and connecting shaft bearings—a frequent source of complaint—is eliminated. Ball bearings have one undesirable feature. If the bearing fails, the break-down is instantaneous, without warning. The bearing, shafting and coupling must be removed to replace the bearing. The unit must be disassembled and re-aligned, and a sizeable repair bill is again incurred.

Sleeve bearings in this respect are more desirable. If a babbitted bearing goes bad, it will generally run hot, and in many instances, will continue to run hot for months, without necessitating a shutdown. This warning of trouble gives the operator a chance to order any bearing parts required, and to take the unit out of service for repairs when most convenient. A sleeve bearing should be of a vertically split design, which will permit re-babbitting without disassembly of the shafting, and without removal of the outer bearing housing from the supporting beam. With a design of this type, bearing repair costs are cut to a minimum, as the re-aligning expense always incurred when the shafting is disassembled, is avoided. A good vertical sleeve bearing should be fitted with a self-contained oil circulating pump, a stationary external housing, and a liberal oil chamber. The bearing must be oil-tight, otherwise the dry well will be a mess.

External lubricating devices have been used for sleeve bearings. Such devices can be designed to provide satisfactory lubrication, but consume excessive quantities of oil, unless a pump or other device is incorporated, which permits circulation of the lubricant.

Sleeve bearings, internally or externally lubricated, should be fitted with convenient inspection openings, whereby the operator can determine if his oil supply is ample, and if it is in reality reaching the bearing surface, where it is needed.

Compression couplings are a convenience on ball-bearing pumps whenever the shafting must be taken down to gain access to the bearings. These couplings, and any other rotating parts, should have a smooth external surface, with recessed nuts and screw heads, so that no part protrudes which might catch the operator's clothing, resulting in possible injury.

A correctly designed motor stand is helpful, both in erection and maintenance. This stand must have a base large enough to assure rigidity and should be high enough to provide ready access to the coupling at the motor.

The opening around the shaft through the motor and gallery floor, if any, must be large enough to permit the coupling and bearing to pass through, otherwise these parts must be removed from the shaft before the section of shaft passing through the floor can be dismantled or erected.

Both the pump casing and suction elbow should be provided with liberally sized cleanout or inspection hand holes. In spite of bar screens, sewage pumps have been clogged by banana stalks, burlap sacks, long pieces of wire, and, in one instance, a good sized turtle. Care should be taken in the design of the bar screen to prevent the possibility of solids being washed over the end of the screen, or over the top of the screen chamber at times when the inflow to the wet well is above normal.

If the bar screen is built with bars on 2-inch centers, an enclosed non-clogging sewage impeller, designed to pass not less than a 3-inch spheroid will assure satisfactory operation. This type of impeller is generally used on a pump with a 4-inch discharge. There is no good reason why a pump with a larger discharge opening should pass a spheroid larger than 3 inches. If the bar screen for the larger pumps is also built on the 2-inch centers, and the impeller designed to pass not less than a 3-inch spheroid, better impeller proportions and higher efficiency should be attained than those possible with say an 8-inch discharge pump designed to pass 6-inch spheroids.

Impellers to pass solids less than three inches are not generally satisfactory, for a bar screen built on 2-inch or even 1½-inch centers, will permit long rags to pass through between the bars. These rags are likely to roll up into a wad which will clog a pump if the impeller passages are not fairly liberal.

Close clearances between the impeller and the shell are another source of trouble. On one installation, a pump operated for more than two years with no clogging trouble, and then proceeded to clog twice within a week. The trouble was not really clogging, but was due to rubber which found its way between the clearance ring and the impeller, rolled up and jammed the works. The impeller was removed, the flat surface riding against the clearance ring rounded off, and the difficulty cured.

The bearings and shaft for the pump proper should be at least as large in diameter as the connecting shafts and bearings. The pump thrust bearing should be provided with an adjusting nut and locking device which permits raising and lowering of the impeller to adjust the clearance between the impeller and the lower sideplate of the shell. This adjustment can be facilitated if the manufacturer so locates the cleanout openings in shell and suction elbow as to permit checking the clearance with a feeler gauge, and if the housing of the thrust bearing is designed to permit easy removal for access to the adjusting nut. A removable wearing ring should be provided on the lower sideplate, as some wear is bound to occur at the point where the clearance between the sideplate and the impeller is a minimum. This ring is especially desirable in a pump in which the lower sideplate is cast integral with the pump base and suction elbow.

If ball bearings are used on the pump, a split bearing yoke will be helpful to the operator if a bearing must be replaced.

A stuffing box of liberal proportions is desirable, fitted with a clear water seal, especially on plants where considerable sand is handled, due to infiltration. The water seal keeps the grit out of the packing, thereby prolonging the life of the pump shaft. To limit the quantity of clear water used for sealing purposes, a simple solenoid valve can be installed

in the clear water line, wired to open only when the pump motor is operating.

Bronze impellers are generally used, but cast iron impellers are giving satisfactory service at many plants. A cast iron impeller costs less and is likely to stand up better against erosion, where large quantities of sand or other gritty material is handled.

A vent line, not less than ½-inch in diameter, should be run from the pump shell back to the wet well. This line is used to release air from the shell. This air enters the shell whenever the level of the liquid in the wet well drops below the elevation of the pump shell, and will air bind the pump, if not relieved.

A straight suction connection, as short as possible and the full size of the pump suction opening, between the pump and the wet well, is recommended wherever feasible. Where more elaborate suction connections are necessary, care must be exercised to avoid air pockets. At several stations installed within recent years, two circular wells were used to provide a method of scum and grit collection. A suction connection from each well was made to a horizontal suction header. From this header, three connections were made, one to each of three pumps. Some trouble occasioned by air pockets was experienced, but was cured by proper venting. Where such suction piping is used, the top of the pipe should be maintained in a horizontal plane, and offsets necessary to change from one pipe size to another should be made at the bottom of the piping, where the offset cannot form an air pocket.

The accessibility of vertical non-submerged pumps makes this type of pumping equipment desirable when compared with the best of submerged installations. The equipment must be assembled in the field and erected with care and accuracy. Installation difficulties are practically unknown on units installed by a competent mechanical contractor who can furnish skilled mechanics familiar with vertical pumping units.

Submerged Horizontal Pumps in Dry Well

In many instances, satisfactory installations have been made by utilizing horizontal pumping units in a dry well at an elevation low enough to assure a positive head on the suction at all times.

This type of installation provides the simplest form of pumping unit, as the long connecting shafts and aligning troubles inherent in the vertical non-submerged design are eliminated. The pumps and motors are below the level of the sewage and some care must be taken to avoid any possibility of flooding the dry well, thereby damaging the motors and consequently putting all pumping units out of service. Motors should be protected against moisture, and some ventilation should be furnished to overcome excessive humidity, and condensation on the motors when not

in service. A station of this design should be used only where definite assurance is available that the entire station, including the dry well, cannot be flooded during severe storm conditions.

With the exception of possible trouble due to flooding, and rather unfavorable location for the motors, due to excessive humidity, horizontal pumps in a dry well offer all the advantages of the vertical non-submerged unit, plus lower first cost, and less erection and maintenance trouble.

Care should be taken to install a sufficient number of conveniently located valves in suction and discharge piping to permit repairs to the pump or connections, and to permit shutting off the sewage in the event of leaks in the piping or pump proper.

Horizontal Self-Priming Pumps

While vertical non-submerged pumps have been the popular units in the past, horizontal self-priming pumps are likely to be most generally used in the future.

The horizontal self-priming pump combines the advantages of the vertical submerged and non-submerged type, and is located above the sewage level, hence not subject to damage by flood.

The amount of excavation and size of building required is no greater than that needed on a submerged job, as the dry well is eliminated. The entire pumping unit is mounted on the motor floor, and, consequently, is even more accessible than a vertical non-submerged pump.

The first of the self-priming units offered consisted of a sewage pump and wet vacuum pump, mounted on a common shaft. This construction necessitates operation of the priming pump during the entire time the sewage pump is running.

As a properly designed sewage pump will work under suction lift conditions up to and exceeding twenty feet, the priming unit is required only to rid the sewage pump and suction piping of air during the starting period. After the sewage pump is once primed, any power consumed by the priming pump is simply wasted. An analysis of several small capacity, low head installations showed that the priming pump was consuming more power than that actually needed to pump the sewage.

To overcome the inefficiency inherent in this design, more modern self-priming pumps are now available, using small wet vacuum pumps operating at relatively high speed with independent motors. The vacuum pump motor is connected to automatic control which throws the vacuum pump out of service as soon as the sewage pump is primed. This limits the power required for priming, as well as the wear on the vacuum pump.

The installation of a horizontal self priming pump is a relatively simple matter when compared with the erection of a vertical non-submerged unit.

The sewage pump and motor, as well as the direct-connected wet vacuum pump, can be fully assembled on a heavy bedplate by the pump manufacturer. The contractor must level up this bedplate and bolt it down. After the suction and discharge connections are made, the pumps and motors must be accurately re-aligned. This re-alignment is essential whether or not the equipments were aligned and tested before shipment. Even an exceptionally rugged bedplate will spring to some extent when bolted in place, thereby undoing any alignment that may have been made prior to erection. All piping must be supported independently of the pump shell. The pump base should be fitted with a raised lip edge that will catch all drip from both the sewage pump and priming unit.

Adequate provisions must be made to prevent sewage and solids from entering and damaging the priming pump. A special priming valve is generally used for this purpose. This valve must permit the vacuum pump to exhaust all air out of the sewage pump shell and suction piping, but to avoid clogging, must prevent sewage from passing through the valve to the vacuum pump after the air has been removed. All passages in the priming valve through which sewage may pass must be at least three inches in diameter. A number of excellent priming valves for clear water service are available, which are not suitable on a sewage job, due to small orifices which will be clogged by the solids in the sewage. The priming valve used on a sewage installation should be a valve specially designed for this service.

A supply of clear water for sealing purposes is required by the wet vacuum pump. A clear-water supply tank with float valve must be furnished, either built into the pump base or pump bearing stand, or mounted on the wall of the station to permit gravity flow to the vacuum pump. The clear water supply to this tank must be well above the level maintained by the float valve, so that no liquid can possibly flow back from the tank into the clear-water line under any conceivable operating condition.

The installation of a solenoid valve in the clear-water line, arranged to open only when the priming pump is operating, will limit the amount of water used for priming.

The sewage pump and vacuum pump motors should have separate automatic starters to furnish overload and undervoltage protection to each motor.

Plant operators have experienced some difficulty in determining whether a horizontal self-priming pump, which is running, is actually primed and really handling sewage. At one station, the operator opened the pet cock at the top of the shell at frequent intervals to check up on his unit. The result was a generous spray of sewage about the station and a ruined paint job. An inexpensive pressure gage connected to the

pump shell will avoid this. This gage will show a vacuum during the priming period, and a positive pressure when the pump is in operation.

A positive head must be available on the check valves on the discharge side of each pump to assure seating of these valves. Should these check valves fail to close, the vacuum pumps will tend to draw air out of the discharge as well as suction piping with the result that the sewage pump will never be primed.

Piping must be tight, as air leaks will either increase the time required for priming, or if the leakage is excessive, will entirely prevent satisfactory priming.

The pump manufacturer should furnish the entire unit, consisting of sewage pump and motor, priming pump and motor, priming valves, pressure and vacuum switches, automatic starter, all piping, valves and strainers required between these units, and as much of the wiring as possible, so that the entire unit can be assembled, tested and adjusted prior to shipment.

The pump shell and suction elbow should be fitted with hand hole openings. Liberally sized shafts and bearings are desirable.

Motors should be connected to the pump shaft by a good flexible coupling. It will pay to insist on motors built in NEMA frames, as these motors have standardized dimensions including location of bolt holes, shaft diameter, distance from feet to centerline of shaft, etc. In the event of motor trouble, a motor built in a NEMA frame can be replaced by any other make of motor built in the same frame without change in the pump base or bore of coupling.

Installation difficulties on self-priming pumps will decrease rapidly as soon as contractors and operators become more familiar with this relatively new equipment. In the meantime, manufacturers can help the situation materially by issuing complete and concise erection and operating instructions with their equipment.

Horizontal self-priming sewage pumps should enjoy increasing popularity. With the exception of the priming valve, no new and untried equipment is involved. Even priming valves are now available which have been tested in the field over a period of five years. Operating costs are no higher, the cost of the entire pumping station is much lower than that of a non-submerged job of equal capacity, and maintenance cost, due to the accessibility of the equipment and the elimination of the long connecting shafts and guide bearings, is bound to be exceedingly low.

One installation of self-priming pumps was made at a plant already fitted with vertical non-submerged units. The self-priming units were installed entirely at the manufacturer's expense, to test and develop this type of equipment under actual operating conditions. The operation of the self-priming pumps, as compared with the old non-submerged pumps,

proved so satisfactory that the Borough decided to purchase the entire installation, although under no obligation to do so.

Variable Speed Pumping

The last few years have shown a marked trend toward variable speed pumping. A properly designed variable speed pumping installation will cut the detention period of the sewage in the wet well, and cause a continuous rather than an on-and-off flow through the treatment plant. This results in more favorable conditions for treatment, and permits a reduction in the size of wet well.

The use of variable speed units does not alter the installation problem, but has resulted in some difficulties in attaining proper adjustment of the motor controls. The objective in a variable speed design is to obtain a pumping rate which will vary in a direct ratio with the rate of inflow to the wet well. The control is automatically actuated by a float switch with the result that the motor speed and rate of pumping increases with a rise of water level in the wet well.

This objective can be approached, but cannot actually be attained in practice. If a station is so designed that a slight increase or decrease in the rate of inflow to the wet well causes a change in pumping speed, a condition may be reached where the contactors on the control panel are jumping in and out, to provide the speed change called for, at too frequent intervals. Assume a relatively small wet well, and a rate of inflow of 450 g.p.m. With one pumping step at 400 g.p.m. and another at 500 g.p.m., it follows that the pump will change operating speed between the 400 and 500 g.p.m. If the capacity of the wet well is small, and the increase in water level necessary to cause a change in speed also small, the pumping speed will alternate between the 400 and 500 gallon point at surprisingly frequent intervals. On such a station, the momentary increase in flow due to a periodic discharge from an industrial plant or other source, even though of short duration, will also cause the pump to change its operating speed very rapidly through one or more steps, only to slow down again just as rapidly after the momentary surge passes. Such conditions are undesirable, and can be eliminated by providing more liberal wet well capacity and fewer changes in the rate of pumping, so that the wet well will have sufficient storage capacity to take care of momentary fluctuations in flow.

Some saving in power can usually be realized on a variable speed installation. The total work done by the pump is a function of the gallons per minute handled and the total dynamic head against which the pump operates. The total dynamic head is the sum of the static head and the friction head. The static head remains a constant irrespective of the pumping rate, but the friction head decreases approxi-

mately as the square of the capacity. It follows, therefore, that the greater the ratio of friction head to total dynamic head, the greater the saving possible by pumping at reduced capacities. Some of this potential saving is lost due to lower efficiency of the motor when operating at reduced speed with resistance in the circuit. The most economical pumping rate for any valuable speed installation can readily be determined by calculating the kilowatt input to the motor per million gallons pumped, over the range of capacities under consideration. Care should be taken to obtain motor efficiencies based on output over input, not the conventional calculated motor efficiencies quoted by most motor manufacturers.

Testing New Pump Installations

In testing sewage pumps on a new installation, we invariably find the pumping equipment handles capacities considerably in excess of those called for in the specifications. The pumps are designed for the exact specified conditions and meet both capacity and head requirements on shop test within reasonable limits.

The reason for this is that engineers quite correctly use friction tables based on fifteen to twenty-year old pipe. These tables show values fifteen to twenty-five per cent higher than the actual friction loss in new pipe. As a result, the calculated total dynamic head is not present, and the pump must handle a somewhat higher capacity against the lower head existing while the piping is new and smooth, and free from all sedimentation.

In addition, the capacity specified usually exceeds that required by some twenty to twenty-five per cent, as a pumping station generally is designed to meet the anticipated requirements some twenty years hence.

Considering the margin gained due to lower friction on new pipe, plus the factor added for increased future demand, a new plant often operates at capacities from twenty to forty per cent in excess of actual requirements.

To illustrate, let us assume we have a small new pumping station designed for constant speed operation at 400 g.p.m. against 25 ft. static and 25 ft. friction head, or a total dynamic head of 50 feet. The 25 ft. friction head is based on the losses in 20-year-old pipe. The actual loss in new pipe will be considerably lower, probably about 20 feet. The actual head present when pumping at a 400 g.p.m. rate will, therefore, be only 45 feet. As the pump is designed to deliver 400 p.g.m. at 50 ft., it will handle a larger capacity when the system is new, the exact delivery depending on the pressure characteristic of the pump. A pump operating under these conditions might be expected to handle approximately 430 g.p.m. against 48 ft. total dynamic head or 25 ft. static, plus 23 ft. friction head.

The 400 g.p.m. capacity specified is not the capacity actually required on the new plant, but the ultimate capacity actually needed perhaps twenty years hence, based on an assumed growth for the community. It is not unlikely that a capacity of 300 g.p.m. will be found ample for the first five years or more of operation.

Pumping at this lower rate will necessitate a longer period of operation for the pumps, and a more nearly continuous flow through the plant, thereby tending to provide more satisfactory conditions for treatment.

A saving in power will also be effected, for if we have a friction head of 23 ft. when handling 425 g.p.m., this head will be decreased to 11.5 ft. when handling 300 g.p.m. The static head remaining constant at 25 ft., the pump must, therefore, operate against 48 ft. at the 430 gallon rate, but only against 36.5 ft. at the 300 gallon rate. On this basis, the actual work done to move 100 gallons at the 300 gallon rate is only 76 per cent of that required at the 430 gallon rate.

In most instances, where this condition is encountered, the pump manufacturer can furnish a special impeller to permit a decrease in pump capacity and head, as required to meet the characteristics of the system, with little or no decrease in pump efficiency. The constant speed induction motor, generally used, has a fairly constant efficiency curve between three-quarters and full load, so that the pump and motor furnished for the designed capacity can be used with a smaller impeller to permit pumping at a reduced rate, thereby making possible a power saving which may vary from 10 to 30 per cent.

This saving in power costs will more than compensate for the expense in purchasing and installing the special impeller. The pump can be refitted with the original impeller at any time the demand increases sufficiently to warrant pumping at a higher rate. The operating costs of many constant speed plants, where pumping equipment is oversize for immediate needs, can be materially reduced by this procedure, provided the friction head is large enough to make a saving possible.

Centrifugal Sludge Pumps

Mechanical difficulties encountered in installing centrifugal sludge pumps are for all intents and purposes, the same as those which may be experienced on a sewage pump.

Sludge, due to the much greater concentration of solids, requires special pump construction. During the settling process, solids are likely to stratify. As a result, a pump handling raw sludge may be called upon to handle a liquid containing a very large percentage of rags, which may enter the pump suction as balls or wads. Provisions must be made to break up these solids. This can be accomplished externally by a screw or worm feed or by special internal construction, by utilizing a design

incorporating an impeller with cutting edges, which acts as a shredder, in addition to accomplishing the normal functions of a pump rotor.

Digested sludge is likely to cause less trouble than raw sludge, due to elimination of rags in the digesting process. Suction lift should be kept to a minimum, due to gases likely to be liberated by sludge under the vacuum needed to operate under high suction lift.

In some instances, standard sewage pumps have been used successfully on sludge. The fact that one plant operates successfully should not be considered evidence that a standard sewage pump will handle sludge at every plant. The nature of the sludge will vary, depending upon whether it reaches the pump in a raw or in a digested state, the concentration, the nature of solids in the sewage, and the efficiency of the bar screens in eliminating the solids. For a sludge pump application it generally pays to purchase a pump designed to handle sludge.

Discussion

By Grant M. Olewiler

Ardmore, Pa.

Our experience in Lower Merion Township has not included vertical submerged pumps and I must, therefore, pass over this class with the brief comment that having at times been forced to work in manholes where sewage, because of a stoppage, had risen to heights greater than the height of a man, I have the greatest sympathy for any man who must attempt to make necessary repairs.

Our municipality has in use at present two stations equipped with vertical non-submerged pumps, one station with horizontal pumps located in a dry well below the level of the sewage, and two stations with horizontal manually operated pumps located above the level of the sewage.

Vertical Non-submerged Pumps.—I heartily agree with the author that erection of the pumps should be entrusted only to skilled mechanics and recommend to you the requirement that levelling pads be provided on the shell, as much question arises over the matter of the setting of the pump after it is in operation for some time or after repairs have caused the pump to be taken apart. Suitable, oversize, solid foundations are also a necessity which should not be overlooked.

The intermediate shafting with its bearings has been a source of trouble to us. The original equipment in one station, where no bearing had been provided, although the distance between the motor bearing and pumping bearing was less than seven feet, began to whip and became so bad that it was necessary to install a guide bearing before the trouble could be corrected.

Bell-and-spigot pipe has been used on the suction side, as suggested, and found preferable to a rigid joint, although too great care cannot be taken in the alignment of the pipe connections both on the suction and discharge sides of the pump.

Again I heartily concur with the author in urging installation of shafting designed not upon the theoretical loads which it may be called upon to support, but upon the experience that the original cost of the shaft is a small item in comparison with the maintenance in cases where the shaft develops a tendency to whip or wear bearings.

I would greatly appreciate grease lubrication of the bearings, as our experience is that considerable oil is thrown on all nearby objects.

Split sleeve bearings are also favored for the reasons outlined in the paper.

In the matter of hand holes, both in the pump shell and in the suction elbow, I would urge that no pump be considered without these openings.

Checks of the clearance between the impeller and the pump casting should be made whenever the pumping pressure begins to diminish as our experience is that unless the clearance is kept to a minimum the pumping efficiency suffers greatly.

The author suggests a stuffing box of liberal proportions. In the case of our latest installation (1928) the operators state that the packing space is so large that the packing acts as a brake lining upon the shaft if the glands are the least bit tight and if not tightened to this point they leak sewage.

Cast-iron impellers are in use at our stations and seem to wear well against the sand which is admitted to the sewer, in most cases washed in through openings in manhole covers.

In addition to the trouble caused by the length of the shafting between the motors and pumps, my experience has been that it is more difficult to impress the operator with the desirability of having the "cellar" kept as clean as the operating floor, largely because it is not generally seen upon entering the pumping station.

For this reason I would favor a dry well with horizontal pumping units set at an elevation to assure a positive head on the suction at all times.

The author raises the question of flooding this type of installation. Our one station of this character was erected in 1924 and to date has never been flooded. In this station the dry well is surrounded by an operating balcony which projects only a short distance into the dry well space leaving a practically unobscured opening to the roof. The location of the heater in the dry well together with ample window space above the operating balcony tend to keep the machinery in good condition.

Since Lower Merion Township disposes of its sewage through the

city of Philadelphia and has no treatment plant, we are not blessed with the trials and tribulations which attend sludge pumping and have had no experience with this equipment.

The author, as a representative of a company which must keep in step with modern progress, now goes into the latest developments, the self-priming and variable speed pumps.

Building activity prior to 1929 had opened practically all unsewered watersheds which can be pumped into the sewers of Philadelphia and I must, therefore, state our inexperience with these newer types of pumping installations.

Since this paper is one on experiences with sewage pumping, I will digress a bit from the original paper and recall to your minds the original type of pumps.

In 1904 Lower Merion Township, having established a sewer system which included two pumping stations, commenced operation of these plants.

Mill Creek Station, pumping against a theoretical head of 250 feet, was equipped with two triplex plunger type pumps operated by engines using gasoline or illuminating gas as fuel. If any operator of present-day pumps considers the cleaning of centrifugal pumps an odious task, let them be consoled by the following: Each pump was supplied with 96 poppet valves any one of which might become clogged at a moment's notice by rags or pieces of rubber becoming caught between the valve guide and valve stem. The consequence was a rapid decrease in pumping pressure and the only cure was to take off the cover plates and fish until the offending material could be removed, generally by tearing to small pieces by the operator who in order to reach the valve had to insert his hand into the opening, often to elbow length. To add to the joys of the superintendent, the sand being pumped would rapidly score the cylinder walls and allow the pressure to drop because of leakage back past the rings.

The other station, with a much lower head and less capacity, had but 48 valves to cause trouble, while the leakage around the piston was not so pronounced.

As the use of the system increased it became necessary to replace the pumps. A centrifugal pump, belt driven by an Otto Gas Engine operated on fuel manufactured from hard coal, was next installed to replace one of the triplex pumps. This was a ponderous piece of machinery with fly wheels about ten feet in diameter and included an oven, scrubber, and storage space for gas. The gas making room was a very hot and dirty place due to the fine ash covering everything, comparable to the stoking room of a refuse incinerator.

Gas leaks were created by the action of the gas upon the rivets and

bolts, while a constant watch had to be kept to insure a gas of proper quality. The engine was fired by a magneto which furnished its own thrills, often going dead at most inopportune moments. The engine was started by compressed air stored by the engine while running. In case the engine did not start before the compressed air became exhausted, the fly wheel had to be moved to the firing point by means of a bar. The pump, which was located above the level of the sewage, was primed by admitting sewage from the pressure main to exhaust the air in the pump. The drive belt, which was quite large, ran with considerable play on the slack side and someone decided that an idler should be used. One was purchased and applied, with the result that it revolved so rapidly that it caught on fire and set the belt afire before the pump could be stopped. At another time the belt broke—and it is not hard to imagine the result.

To add to the pleasure of operation, the constant leak of gas required the opening of all doors and windows in even the most severe winter weather and one never knew when he might visit the station and find the operator wandering through the neighboring fields or woods in a gas-crazy condition.

Conditions were greatly improved when an electrically operated centrifugal pump replaced the other triplex pump and the use of the gas-engine driven pump was reserved for times when the capacity of the motor driven pump was not sufficient to care for the flow.

The gas-engine-driven pump was next replaced by another motor-driven centrifugal pump and a third motor-driven centrifugal pump was installed so that now pumps of three various capacities can handle any flow which may be encountered, short of an exceptionally heavy rain of several days duration.

In my mind I have always coupled the pressure main with the pumps and would advise that extremely careful inspection be given to joints. Above all, be sure that the pipe is centered. Joints may be caulked should they show a leak, but the burning out of the entire joint in a wet ditch to remove the lead and re-align the pipe is a job of major proportions.

In the original installation of the pressure main at the Mill Creek Station, changes in line were made without bends, with the result that one side of the joint has hardly enough room to insert a screw driver, and to keep lead in such a joint requires patient caulking. In one place the joint in the pipe comes in the middle of a creek and when a leak appeared it was necessary to lie in the water and caulk between breaths.

Another caution which I would add is: do not consider too lightly the human element in the operation of pumping stations. Someone must keep an eye on the equipment, remove stoppages in the pumps or air

relief lines, keep screens cleaned, and in general care for the place. Remember, a motor burned so that it must be rewound, is more expensive than the salary of a steady man for several months.

Our policy in operating "Automatic Stations" is to have a man there during the daytime, to operate the collecting wells so that only the overflow through the cleaning valve will reach the second well, and to pump from the first well during the daytime while the pump from the second well is operated during the night.

Another device used to continue operation of the plant even if one pump and motor should fail, is to have the switch wired so that rise of sewage in the wet well above a certain level will automatically cut out the first motor and start the second.

Stand-by charges of the electric company are practically halved by the installation of a de-energizing relay, which makes it impossible to use both motors at one time when two units are installed, but one is used only as a relief unit.

When the pump floor is located below the wet well level, it is advisable to install a sump pump operated by an electric motor, as well as manually operated suction lines from the pump suction side, as the installation of a water-power suction lift has been found to be expensive, unless water is very cheap.

The pressure mains have not caused trouble for some time. Centrifugal pumps are now in use, three of the five stations operate with a positive head on the suction side of the pumps, life seems worth living, and I breathe a sigh of gladness as I think the "Good Old Days" are gone forever.

Editorial

THE CHEMICAL COMMITTEE REPORT

The Committee Report in this issue, "Chemical Treatment of Sewage," is much the longest article that has even been printed in the JOURNAL. The length is justified, however, in our opinion, by the importance of the subject, the interest of both technicians and laymen in chemical treatment of sewage, and the time and effort spent on the Report by the members of the Committee. It has seemed to the Editor that the entire Report should be published and preferably in one issue. Thanks are due the American Public Health Association for the prompt release of the Report. New developments are occurring so rapidly in the field of chemical treatment of sewage that immediate publication seemed desirable, in order to take stock of the developments to date and to serve as a foundation for future information on the subject.

Some critics of the Report will claim that the importance of chemical treatment has been exaggerated, others that it has been minimized, but undoubtedly the majority of readers will feel that the comments and conclusions are fair and impartial, and that a sincere effort has been made to present a picture of the history and status of chemical treatment of sewage, undistorted by personal or commercial interest.

The re-birth of chemical treatment, as traced through the Report, up to the culmination in the list of plants in which chemicals are now used or are planned to be used, is undoubtedly the outstanding feature of American development in sewage treatment during the past few years. European sewage authorities are rather astounded at the great interest shown in America in chemical treatment of sewage, and apparently they seem to think that the developments here in recent years have occurred, in part, because of lack of a sufficient background of experience in use of chemicals. In England, and to some extent in Germany, chemical treatment was in vogue for several decades before the advent of biological treatment, and this history is recorded in the Committee Report. Undoubtedly there was a large amount of publicity and propaganda for chemical treatment several years ago in the U. S. by enthusiasts, promotors and inexperienced investigators, but this period of extravagant claims, expensive but abortive investigations, and high-pressure salesmanship is beginning to wane and a sound basis of practice is now developing for the use of chemicals in American sewage treatment. The Committee Report may be helpful in clearing the way for a reasonable and permanent development of chemical treatment of sewage in America.

After all, the birth or re-birth of any new major system of sewage treatment is characterized by an initial period of extravagant claims, followed by a gradual realization of a few major obstacles, and finally by a permanent and conservative practice in which the limitations as well as the advantages are appreciated. The development and use of septic tanks, trickling filters, activated sludge and heated separate sludge digestion have passed through these cycles and chemical treatment is undoubtedly passing through a similar cycle.

It is interesting to note the comments of European authorities on the present interest in chemical treatment in the United States. Dr. Imhoff visited this country last year and he has recently described briefly ("Chemical Sewage Treatment in America," *Gesundh. Ing.*, **39**, 601, Sept. 28, 1935) his impressions. With reference to the significance of the new American trend on sewage treatment in Germany, his opinion is as follows:

"In Germany, the three following possibilities are available for the use of chemical treatment:

"(1) If fairly complete purification of sewage is necessary, but biological treatment is interfered with by industrial wastes.

"(2) If 'seasonal' use is required, that is, most of the year settling alone is sufficient and only occasionally more complete treatment is necessary, for example, during the bathing season.

"(3) If an old clarification plant is in use, in which the degree of treatment needs to be improved with the least possible expenditure."

It is interesting to the writer to note how closely this prediction agrees with his conclusions, presented at the Indianapolis meeting of the American Public Health Association two years ago ("Recent Advances in the Chemical Treatment of Sewage," *Am. Jour. of Pub. Health*, **24**, 25, January, 1934.)

Dr. Hermann Bach, at Essen, is very conservative in his opinion of the function of chemicals in sewage treatment. He has written several articles on chemical treatment, in which he claims that chemicals fail to remove the nitrogenous matter in sewage and that chemically precipitated sludge is difficult to handle. In his most recent paper (*Chemiker-Zeitung*, **85**, 861, October 23, 1935) Dr. Bach states:

"(1) Even with the use of ingenious mechanical devices, flocculating chemicals cannot remove decisive amounts of the albuminous organic matter in sewage.

"(2) With all chemical processes the sludge, apart from its quantity, is of impaired quality and more difficult to dispose of."

Dr. Bach is rather outspoken, so much so that in his discussion of the Jung Process (*Vom Wasser*, **8**, 84, 1934) he referred to chemical treatment as "apparent," biological as "true"; the Editor, Dr. Haase, suggested he meant "artificial" and "natural"; Dr. Jung closed by saying

that he might as well stick to the words which are inherently self-explanatory "chemical" and "biological."

In England, H. C. Whitehead and F. R. O'Shaughnessy have recently discussed sewage treatment ("Factors in the Design of Sewage Disposal Works," *The Surveyor*, **88**, 404, October 18, 1935). They refer to the outlook for chemical processes as follows:

> "It seems very unlikely that they (*i.e.* chemical methods) will play any other part than the already well-known and quite useful one of accessory processes for the relief of the load on oxidation plants, the reduction of pollution, or for partially treating difficult trade wastes and sewages."

Another British authority, Mr. John H. Garner, now President of the Institute of Sewage Purification, has had considerable experience in the use of chemicals in the West Riding of Yorkshire, where more than 400 sewage treatment works are under his supervision, in some of which chemicals are used. It is therefore of interest to note these statements made by him (*Reports of the Progress of Applied Chemistry* **18**, 702, 1934):

> "Before the development of biological processes of after-purification, chemical precipitation played an important part in sewage disposal, but later fell into disfavour because of the difficulty in dealing with the large volumes of sludge produced. There are signs that improved methods of sludge treatment are removing some of the prejudice against chemical precipitation and, in the writer's opinion, some importance must be attached to this trend, as by chemical treatment it is often possible to remove from sewage the greater part of its polluting constituents."

These quotations from foreign authorities indicate the interest with which the revival of chemical treatment in America is being watched abroad. In view of this interest, the Report of the Chemical Committee will undoubtedly be studied carefully by our European readers.

In addition to the members of the Committee, which has been a standing committee of the A. P. H. A. for a number of years, many other well-known American engineers and chemists in recent years have made valuable contributions to the advancement of theory and practice of chemical treatment of sewage and industrial wastes. These men include Wellington Donaldson, Linn Enslow, Harry Hendon, S. I. Zack, Richard Gould, S. A. Greeley, Prof. Charles Gilman Hyde, L. F. Warrick, M. W. Tatlock, G. H. Gleason, W. C. Laughlin, Mark Owen, Elson H. Killam, L. L. Hedgepeth and others who, if overlooked by the writer, deserve his apology.

In conclusion, a word of appreciation should be spoken for Mr. Pearse, the Chairman of the Committee, who has worked so long and so conscientiously on the preparation of the Report. The Committee and the sewage treatment profession owe him a debt of gratitude for the energy and skill with which he has directed the preparation of the Report.

F. W. MOHLMAN

Proceedings of Local Associations

NEW ENGLAND SEWAGE WORKS ASSOCIATION

NEW YORK STATE SEWAGE WORKS ASSOCIATION

First Joint Meeting, Schenectady, N. Y., Oct. 4–5, 1935

The first joint meeting of the New England Sewage Works Association and the New York State Sewage Works Association, held on October 4 and 5, 1935 at the Hotel Van Curler, Schenectady, N. Y., proved to be one of the highlights in the history of Sewage Works Association meetings and set a mark of attendance and program that will be difficult to surpass. Three hundred and twelve members and guests were registered.

Although the meeting did not open officially until 10:00 A.M. on Friday, October 4th, the displays of sewage works equipment provided by some twenty-six manufacturers were open for inspection at 6:00 P.M. on Thursday evening, October 3d. A large number of early arrivals availed themselves of the opportunity to inspect the exhibits and talk with the manufacturers. The exhibits were also open during Friday and on Saturday morning and the program was arranged to provide ample opportunity for their inspection. The following manufacturers presented displays of their products:

Norton Company
Lord & Burnham
American Brass Company
Carborundum Company
Hardinge Company
Link Belt Company
General Electric Company
Wailes-Dove-Hermiston Company
Pardee Engineering Company
Pittsburgh Equitable Meter Co.
Chain Belt Company
W. & L. E. Gurley
Robinson Clay Products Company
Wallace & Tiernan
L. A. Weston
Turbine Sewer Machine Co.
Merrimac Chemical Company
U. S. Pipe & Foundry Co.
Inertol Company
The Dorr Company
Royer Foundry Machine Co.
Oliver United Filters
Mine Safety Appliance Co.
Chicago Pump Company
Builders Iron Foundry

Registration was scheduled for 8:30 A.M. on Friday morning. Shortly before 10:00 P.M. the various members of the two associations and their guests, including fifty-eight ladies, were taken by bus, fur-

nished by the courtesy of the General Electric Company, to Rice Hall at the General Electric works for the first session. The meeting was formally opened by President Morris M. Cohn of the New York Association, who introduced Mr. R. C. Muir, Vice-President in charge of engineering of the General Electric Company. Mr. Muir welcomed the association to Schenectady and to the General Electric works and invited all to visit station WGY and other parts of the plant.

The first part of the morning program was devoted to a journey through the General Electric "House of Magic." Mr. L. A. Hawkins, Executive Engineer of the General Research Laboratory introduced Mr. Ellis Manning, who explained in a most interesting and entertaining manner the marvels presented. The scientific mysteries which were explained and demonstrated proved to be one of the most valuable and enjoyable parts of the entire program.

At the conclusion of the demonstration, President Cohn opened the business meeting of the New York State Association. Following a very brief business session, the meeting was turned over to Vice-President Guy E. Griffin of the New England Association, who presided at the business session of that association in the temporary absence of President Gordon M. Fair. Mr. Griffin called upon Mr. Stuart E. Coburn, Chairman of the nominating committee, to report. Mr. Coburn presented the following nominees for the various offices of the Association:

President, Guy E. Griffin, Greenwich, Conn.
Vice-President, Stephen M. Gage, Providence, R. I.
Secretary-Treasurer, F. W. Gilcreas, Albany, N. Y.
Directors, John H. Brooks, Worcester, Mass.; LeRoy W. Van Kleeck, Hartford, Conn.

It was voted that the secretary should cast one ballot for the slate of officers presented by the nominating committee. This was done and the above officers declared elected. This concluded the business session of the New England Association.

Following adjournment of the morning session, the members were again transported by bus to the Hotel Van Curler for luncheon. From there the ladies were taken by bus to the Riverwood Inn for luncheon and an afternoon of bridge. Several of the ladies, who preferred a trip to WGY and the shops of the General Electric works, left Riverwood directly after luncheon by bus and enjoyed a trip through the broadcasting station and other interesting parts of the plant.

The Associations assembled for luncheon at one o'clock at the Hotel Van Curler. Following luncheon, President Cohn introduced the Honorable Henry C. Fagal, Mayor of Schenectady, who welcomed the two associations and extended the hospitality of the city and the facilities of its government to assist in making the meeting a success. President

Gorden M. Fair of the New England Association replied to Mayor Fagal's greeting. The luncheon then adjourned to permit time for those in attendance to inspect the manufacturers' exhibits, which were on display in the adjoining solarium and garden room.

Promptly at 2:30 P.M. the afternoon session was called to order by President Fair, who presided. As the first speaker on the program he introduced Dr. F. W. Mohlman, Chief Chemist of the Sanitary District of Chicago, who presented a most interesting and instructive paper on the "Disposal of Sewage Solids." This paper was illustrated with lantern slides. President Fair opened the discussion of Dr. Mohlman's paper.

The second paper of the afternoon "Cost Records for Maintenance and Operation of Worcester Sewer System and Sewage Treatment Plant" by John H. Brooks, Supt. of Sewers and Roy S. Lanphear, Supervising Chemist, was presented by Mr. Brooks. The discussion of this paper was opened by Glenn D. Holmes, Consulting Engineer, Syracuse, N. Y., and a general discussion from the floor followed.

President Fair then relinquished the chair and President Cohn of the New York Association continued the afternoon program, introducing as the third speaker, Professor Earle B. Phelps of Columbia University, who spoke on the "Fundamentals of Biochemical Oxygen Demand in Sewage Treatment and Stream Purification." Following this discussion, President Cohn introduced Newell L. Nussbaumer, Buffalo, N. Y., who presented the fourth paper entitled "Unique Features of Walden Sewage Treatment Plant." The discussion was opened by J. C. Brigham, Albany, N. Y. The meeting then adjourned to permit further inspection of the manufacturers' exhibits and a social hour preceding the evening program.

At seven o'clock, 260 members and guests, including the ladies, assembled for an informal dinner in the banquet room of the hotel. Dinner music was furnished by the Schenectady High School String Ensemble. President Cohn of the New York Association acted as toastmaster and introduced as the guest speaker, Dr. Paul B. Brooks, Deputy State Commissioner of Health, Albany, N. Y. In place of a formal address, Dr. Brooks presented a very entertaining and timely skit, illustrating the radio approach in public health education in matters pertaining to problems in sanitation.

President Cohn then introduced Mr. A. F. Dappert of Albany, who under the alias of Mr. Dappertine entertained the assembly with some exceedingly clever and artistic charcoal sketches concluding his part of the entertainment by reproducing on his drawing board excellent likenesses of Mr. Cohn, Professor Phelps, and Mr. L. H. Enslow. Following this part of the program, dancing was enjoyed which was later inter-

rupted to permit the members and their guests to enjoy an excellent floor show. Dancing was then continued until after midnight.

At 7:30 A.M. on Saturday morning a large number of those in attendance gathered in the dining room to view moving pictures illustrating the operation of a number of sewage treatment plans in New York State. These pictures had been prepared by the Division of Public Health Education and the Division of Sanitation of the State Department of Health and were shown by Mr. Crist of the former division and explained in a running talk by Mr. C. C. Agar of the Division of Sanitation.

Shortly after 8:00 A.M. 139 members gathered for the well known sunrise breakfast of the New York State Sewage Works Association. This was followed by a most valuable round table discussion conducted by C. C. Agar of the New York Association and S. E. Coburn of the New England Association. At the close of the round table discussion, Mr. Cohn gave a brief description of the Schenectady plant, which was to be visited later in the morning, and distributed literature descriptive of that plant and also of the Canajoharie Combined Sewage Treatment and Refuse Disposal Plant which was also included in the inspection tour of the day.

At ten o'clock an auto caravan of sixty-five cars carrying 232 persons assembled in front of the hotel and was conducted under police escort to the Sewage Treatment Plant at Schenectady where Mr. Cohn and other officials of the plant acted as guides for the inspection. The auto caravan under state police escort assembled, this time for a trip to Canajoharie for luncheon at the Hotel Wagner, as the guests of Mr. Bartlett Arkell, President of the Beechnut Packing Company. All enjoyed a trip of inspection to the Beechnut Packing plant and the famous art gallery and library of the Beechnut Company, located in Canajoharie.

As the concluding part of the program, the assembly adjourned to the Canajoharie Sewage Treatment Plant and Refuse Incinerator to inspect the novel features of this recently constructed plant. Following this inspection, the members and their guests proceeded to their homes, and the first joint meeting of the New England and the New York State Sewage Works Association was adjourned.

F. W. Gilcreas, *Secretary-Treasurer,*
N. E. S. W. A.

A. S. Bedell, *Secretary-Treasurer,*
N. Y. S. S. W. A.

Editor's Note. The reference above to Mr. Cohn's "brief description of the Schenectady plant" hardly does justice to his witty yet informative remarks. In order to preserve for posterity "Cohn's Schenectady Address" it is printed below in full.

THE SCHENECTADY SEWAGE TREATMENT WORKS

A DESCRIPTION

"Cohn's Schenectady Address"

One score and one year ago, our city fathers brought forth upon this community, a new sewage disposal plant, conceived under pressure of public and state health department opinion, and dedicated to the principle that all sewage and water are not created equal. We are now engaged in a Grant War with the Federal Administration of Public Works, testing whether that sewage plant or any sewage plant so conceived and so dedicated, should be reconstructed.

We have met upon the scene of that Grant War. We have come to inspect the old and aged plant for which our city fathers laid down some $400,000, before the leisurely Imhoff tanks give way to separate sludge digestion units with their modern high-pressure way of doing things; before the tedious hand skimming of tanks gives way to the technocratic mechanical sludge and scum collecting equipment.

This fair Gateway to the West has a population of some 95,000 persons, and a sewage flow of some 14 m.g.d. In 1914, when the present works was constructed, through the joint conspiracy of freeflowing quicksand and less liquid funds, Schenectady was provided with a plant of but 6 m.g.d. capacity, with the shallowest Imhoff tanks in captivity and minimum-depth trickling filters. Subsequent minor reconstructions have enabled us to squeeze some 9 m.g.d., of sewage through this plant. The balance of the sewage enters the Mohawk river, to the edification of the fish and the shocking of the senses. This inadequacy the city is now proposing to overcome in its proposed new plant, by the grace of PWA and a willing Common Council.

The present plant has been widely publicized, because of its pioneering activities in the municipal treatment field and an active program of study and research. The treatment system consists of a pumping station where some 6 m.g.d. of sewage is low-lifted to join some 3 m.g.d. of gravity flow in the trunk sewer; a hand-cleaned bar rack; nine shallow Imhoff tanks of 14 ft. working depth and 2½ hour detention period; three dosing tanks; three acres of trickling filters; and an emergency pumping station for pumping the final effluent against the periodic flood stages of the diluting stream. Sludge is dried on open sand beds, and successfully sold to farmers as a fertilizer.

The proposed new plant will be an economical conversion of the existing plant into a 15 m.g.d. separate sludge-digestion works. The present bar rack will be converted into a mechanically-cleaned rack, floated operated. Screenings will be shallow-plowed for final disposal, a practice now successfully carried out. Facilities can be provided for incineration of screenings.

Six Imhoff tanks are to be converted into plain settling tanks, equipped with mechanical sludge and scum collecting mechanisms. Sludge will be digested in two 60 ft. dia. by 24 ft. deep digesters, fitted with stirring mechanisms and the usual heating equipment. Three Imhoff tanks will be converted into second-stage digesters. Gas will be collected, stored in a gasometer floating on the line and utilized for the production of light and power for buildings and equipment, and heat for the digesters and buildings. Power will be produced by burning the gas under a high pressure boiler and utilizing the steam for the operation of a steam turbo-generator. The generator condensate will be used for heating the digesters and bled high-pressure steam will heat the buildings.

An existing sludge bed battery will be augmented by an acre of open beds produced from an acre of trickling filters. Filter operation will be suspended upon approval of the State Health Department of a policy of primary treatment for the Mohawk river valley. Sludge can be dried on a small vacuum filter designed for caring for overload and for research work.

I hope that this short review of the old and the new will give you a clear conception of our present practice and proposed policies.

The existing plant is decrepit. Paint is holding much of it together. Respect its wrinkles and its graying hair. I find myself in the ungraceful position of being an advocate for clean, well-kept plants, and lots of public visitations, and having a works for which I must apologize. However, we were pioneers in Imhoff tank-trickling filter operation. Schenectady will yet take its place among the new, modern works.

CENTRAL STATES SEWAGE WORKS ASSOCIATION EIGHTH ANNUAL CONVENTION

Urbana-Champaign, Illinois, Oct. 25–26, 1935

The Eighth Annual Convention of the Central States Sewage Works Association was held at Urbana, Illinois, October 25 and 26, 1935. There were 136 registered members and guests. Although other meetings of the Central States Association have had larger attendance, none of the previous meetings equalled this one in class of entertainment or interest in the technical program. The success of the meeting was almost entirely due to the skilful preparations made by Gus Radebaugh, Secretary, and Prof. H. E. Babbitt, Chairman. Gus has had lots of experience in handling sewage works meetings, but he fairly outdid himself with this one. Likewise the genial toastmaster, Prof. Babbitt, was the life of the party at the annual banquet Friday night.

President M. Starr Nichols opened the technical program Friday morning, October 25, at 10:15 A.M. The first paper, "Influence of Substrate on B.O.D.," by W. L. Lea and M. Starr Nichols, was presented by Mr. Lea. Most of the listeners were intrigued in advance by the prospect of hearing about a "substrate," but it turned out to be the old bone of contention in B.O.D. work—dilution water. Quite an array of synthetic dilution waters had been used for determining the B.O.D. of dextrose and a paper mill waste. The standard sodium bicarbonate water gave low results for the 5-day B.O.D., but additions of other mineral salts, even in minute amounts, greatly increased the results. Lea and Nichols recommend consideration of a more complex dilution water, particularly for pure carbohydrates such as dextrose, and possibly for paper mill wastes.

The next four papers comprised a symposium on the disposal of garbage with sewage. The first two papers described work at Indianapolis and the latter two were concerned with experimental work at Urbana. Don E. Bloodgood, Engineer in Charge of the Indianapolis Activated Sludge Plant, gave a very interesting paper, "Digestion of Garbage with Sewage Sludge." This dealt with laboratory experiments in which various quantities of garbage and sewage solids were digested. It was concluded that garbage would accelerate the digestion of sewage solids, if used in the proportions expected at Indianapolis (garbage volatile solids only 16 per cent of sewage volatile solids).

Mr. C. K. Calvert, Superintendent of the Indianapolis Sewage Disposal and Garbage Reduction Plants, presented a paper on the plant-scale experiments made during the summer of 1935. This work was carried on with the assistance of Mr. L. M. Tolman of the Jeffrey Manufacturing Company. The grinder was a 10-ton-per-hour Jeffrey hammer mill. Sewage was introduced at the rate of 50 gal. per min. as the garbage was being ground, and the discharged mixture flowed through the grit chamber at an average velocity of 0.75 ft. per second. There was an increase of grit, after addition of garbage, from 3.4 to 13.6 cu. ft. per million gallons. The garbage also caused an increase in skimmings in the primary concentrators from 0.74 to 2.94 cu. ft. per million gallons. In the aeration tanks, there was a considerable increase in B.O.D., requiring more air, but resulting in an inferior effluent. Disposal of solids presented no difficulties as the mixed solids were pumped to the open digestion pits or lagoons. Observation indicated that there was no increase in odor of the mixed sludge. Costs of disposal of garbage in this manner were estimated to be much less than by reduction, but it has been decided to repair the reduction plant at the present time and it will be continued in use.

The third paper on garbage disposal was "An Investigation of the

Amount of Garbage That Can Be Digested with Sewage Sludge." This was presented by W. H. Whitley, Graduate Research Assistant, University of Illinois. Mr. Whitley conducted experiments in bottles and 55-gallon steel tanks, using various proportions of garbage and sewage solids. Quite variable results indicated the need for temperature control and some type of stirring or mixing the digesting solids.

Prof. H. E. Babbitt presented the paper, "Methods of Dosing Sewage Tanks with Ground Garbage." The work described by Prof. Babbitt was carried on in large wooden tanks in the University of Illinois Experiment Station. Additions of ground garbage solids to the sewage treated in Imhoff tanks resulted in very serious increase in suspended solids present in the effluent. When added to the gas vents, garbage solids formed an odorous, objectionable scum. When used in a two-story, heated, circulatory digestion tank, however, the garbage solids digested rapidly, a very large amount of gas was produced, and digestion proceeded rapidly. The continuation of this work is planned. (See below, resolution adopted by convention.)

Mr. Warrick's paper "Treatment of Industrial Wastes in Connection with Domestic Sewage" was presented Saturday morning. Mr. Warrick reviewed the excellent work that is being done in Wisconsin on the treatment of cannery and paper mill waste.

The business meeting Friday afternoon resulted in the election of the following officers for 1936:

President—O. M. Leonard, Indiana;
First Vice-President—H. E. Babbitt, Illinois;
Second Vice-President—F. M. Dawson, Wisconsin;
Third Vice-President—George J. Schroepfer, Minnesota;
Secretary-Treasurer—G. H. Radebaugh, Illinois;
Representatives to Board of Control—Federation of Sewage Works Associations:
W. W. DeBerard—Chicago,
James Ferebee—Milwaukee.

The following resolutions were adopted:

Resolution—In Memoriam

Whereas, Harry F. Ferguson was a past president of this Central States Sewage Works Association and

Whereas, He contributed greatly to the success of this association, and,

Whereas, He was really loved and respected by all the members,

Therefore be it Resolved that this Association in convention as-

sembled express to his wife, Zelda Hensen Ferguson, their deepest regrets over his passing.

Carl E. Schwob (Ill.).
C. K. Calvert (Ind.).
K. L. Mick (Minn.).

Resolution—In Memoriam

Adopted Eighth Annual Convention, October 25–26, 1935, Central States Sewage Works Association, Urbana-Champaign, Illinois.

Whereas, Mr. J. A. Childs, Sanitary Engineer of the Minneapolis and St. Paul Sanitary District, was a faithful and loyal member of the Central States Sewage Works Association for a great number of years, and

Whereas, Mr. J. A. Childs had contributed to the advancement of sewage treatment and disposal in the positions held by him as Sanitary Engineer for the Minnesota State Board of Health and as Chief Engineer of the Metropolitan Drainage Commission of Minneapolis and St. Paul before his illness, and

Whereas, This Association will miss his congenial fellowship and loyalty in their meetings and gatherings,

Be It Resolved that we, the Central States Sewage Works Association, extend to his family and those who were intimately associated with him, our heartfelt sympathy for their great loss in the death of Mr. Childs.

Be It Further Resolved that a copy of this resolution be sent to his family.

Louis A. Geupel (Ind.), *Chairman.*
Paul Hansen (Ill.).
H. O. Lord (Minn.).

Resolution

Research Experiment Station—University of Illinois

Whereas, The research in methods of sewage treatment now being conducted at the University of Illinois is recognized as contributing valuable information to the art and a benefit to the taxpayers of the State of Illinois who have invested several hundreds of millions of dollars in sewage treatment work, and

Whereas, The cost of conducting such research in a proper and adequate manner is thoroughly appreciated by this organization, and

Whereas, It is evident that the Board of Trustees of the University of Illinois has evidently been aware of the value of such research to the health, wealth and welfare of the public, as manifested by the past expenditures made in the support of the work,

NOW, THEREFORE, BE IT RESOLVED, that the Central States Sewage Works Association in convention assembled at Urbana, Illinois, on October 26, 1935, does hereby express its appreciation of this past support and brings to the attention of the Board of Trustees the growing demands being made upon sewage treatment plants, the intricacies of new problems arising, and the need for a more rapid solution of the problems before us, and

BE IT FURTHER RESOLVED, that this Association urges that greater and adequate support be given by the State of Illinois through the University of Illinois to Sewage Disposal Research now being ably conducted by Prof. H. E. Babbitt with wholly insufficient funds.

Louis A. Geupel (Ind.), *Chairman.*
Paul Hansen (Ill.).
H. O. Lord (Minn.).

After the business meeting buses were provided for a trip to the Urbana-Champaign Sewage Treatment Works, the Sewage Testing Plant of the University, and the State Water Survey.

The annual dinner was held Friday night at 6:30. President Nichols introduced Toastmaster, Ringmaster and Hoaxmaster Babbitt, and thereafter the meeting was entertained by addresses, wrestling, boxing and tumbling, vocal solos, and finally by one of the best pseudo-sanitarians on the lecture platform—The Honorable Anton Carlson, Minister of Sanitation of a Scandinavian country. Practically all of the listeners expectantly waited for the Minister to get down to sanitation or sewage, and it was not until nearly the end of his riotous stories that the hoax was apparent—the "Minister" was Axel Christensen, entertainer from Chicago.

The evening meeting was featured, in its serious moments, by the award, posthumous, of the prize for last year's best paper to Mr. J. A. Childs. The prize of twenty dollars was to be sent to Mr. Child's widow, with a letter expressing the esteem in which Mr. Childs was held by all members of the Central States group.

Saturday morning, at 9:00 A.M., a very interesting technical meeting was opened by a paper on and a demonstration of the "Odeeometer," by L. H. Kessler of the University of Wisconsin, and Adolph Wandfluh, Operator of the Sewage Treatment Works of Monroe, Wisconsin. This paper was a continuation of Mr. Kessler's work reported in SEWAGE WORKS JOURNAL, September, 1935.

The next paper, "Diffuser Plate Studies," by A. J. Beck, Principal Sanitary Chemist, Sanitary District of Chicago, dealt with the work done by Mr. Beck at the North Side Treatment Works on the rating of porous plates for air diffusion, the cleaning of plates, a consideration

of the factors which cause clogging, and a study of the size of air bubbles from plates of various porosities. The curves, diagrams and tables, shown by slides, reflected the detailed, careful and extensive work carried on by Mr. Beck.

The next paper, "Magnetite Filters in Sewage Treatment," by S. I. Zack, of the Filtration Equipment Corporation, was an interesting and up-to-date summary of the results obtained at Dearborn, Coney Island, Chicago, and Perth Amboy, with the Laughlin Magnetite Filter, with and without chemicals.

The Association was honored, in the final paper, by Mr. George J. Schroepfer, for years Mr. Child's assistant at Minneapolis, and now Assistant Chief Engineer of the Minneapolis-St. Paul Sanitary District. Mr. Schroepfer explained the sewage disposal problem at the Twin Cities, noting that a total of $6,580,000 has been spent on the project since construction started July 13, 1934. An important feature of Mr. Schroepfer's paper was the announcement that the plant would consist of primary treatment plus provision for infrequent application of chemicals at times of low flow in the Mississippi River, and, moreover, that sludge disposal would consist of vacuum filtration and incineration. This statement is of importance in indicating that the Twin Cities are planning to eliminate digestion of sludge.

Following Mr. Schroepfer's paper, Dr. W. D. Hatfield had an informal round-table discussion of operating problems.

The meeting finally broke up Saturday noon, with a friendly luncheon. Resolutions were adopted thanking the local hosts for the fine hospitality and entertainment features of the meeting. In particular, Mrs. Radebaugh and Mrs. Babbitt were thanked for their gracious entertainment of the ladies. Dr. W. D. Hatfield was also thanked by resolution as a member of the Central States Association, for his faithful and comprehensive work on standard methods of sewage analysis, published in the May, 1935, SEWAGE WORKS JOURNAL.

The final event was the Illinois-Iowa football game, and here the local committee fell down—they permitted Iowa to win.

F. W. MOHLMAN

Reviews and Abstracts

WATER POLLUTION COMMISSION AND GOVERNMENT INSTITUTION FOR WASTE PURIFICATION (THE NETHERLANDS)

By H. J. N. H. Kessener

Annual Report, 1934 (The Hague)

On June 1, 1934, the government installed a Commission, consisting of representatives for two government bureaus, agricultural organisations, fresh water fisheries, Society of Dutch Communities, Union of Drainage Boards and the Director of the Government Institute for Waste Purification, whose duties it will be to review, study, advise and confer with all interested in water pollution, unify the existing rules and regulations, and continue to prepare plans and specifications for sufficient treatment where necessary.

The report deals more specifically with the pollution of a number of streams, canals and public waters, setting forth the degrees of pollution, causes and remedies proposed. Advice given to a number of official bodies and more specifically to industries is reported in more or less detail. Milk waste discharge, slaughterhouse waste, laundry, leather and tannery, and potato waste, continue to be of greatest importance.

A chapter is devoted to the description and analyses of several sewage treatment plants. In previous reports the plants at Groenlo and Winterswijk were described and in spite of the fact that the trickling filters received 40 per cent more settled sewage, the results were highly satisfactory. At Groenlo the average B.O.D. was reduced from 326 to 23 p.p.m. with average nitrate (N_2O_5) of 101 p.p.m. Ripe sludge produced at these two plants had the following analyses:

	Groenlo	Winterswijk
Total solids, per cent	6.0	6.7
Ash, per cent	40.4	41.9
Total N	3.6	3.1
P_2O_5	1.6	1.9
K_2O	0.5	0.4
pH	8.2	8.1

The sludge is sold to neighboring farmers. The dried sludge was moved and piled by unemployed and brought 35 cents per load.

The report contains descriptions of a number of different plans,

specifications and recommendations prepared for municipalities. This work is considered to fall under the regular routine of the Institute.

WILLEM RUDOLFS

RECENT SEWAGE PLANT DEVELOPMENTS CALL FOR FRESH APPROACH TO DESIGN PROBLEMS

BY S. A. GREELEY

Engineering News-Record, **115**, 501–502 (October 10, 1935)

Since 1930 many new developments have occurred in sewage treatment. Screenings are being macerated and returned to the sewage, making finer screens more practical. In larger plants, grit is now generally removed by scraper mechanisms and then cleaned. Grease is removed in some recently built plants. Round tanks are now being used, especially for final sedimentation of activated sludge. Aeration tanks have been widened from a maximum of 22 ft. to 32 ft. 9 in. in the new Chicago Southwest project. This results in material economies. Revolving or travelling distributors are now quite commonly used for trickling filters.

In the field of sludge digestion, the use of gas for power, providing 2/3 of the power requirements for aeration, a wider variety of gas holder covers for digestion tanks, sludge filtration and incineration are major advances.

Chemical treatment is providing an intermediate degree of treatment, giving 70–75 per cent removal of suspended solids and B.O.D., as against 30–35 per cent for plain sedimentation and 85–92 per cent for activated sludge or trickling filters. With such intermediate treatment available, seasonal needs of the receiving stream for a varying degree of treatment and seasonal variations in loading due to industrial wastes can be handled more economically.

R. W. KEHR

CHEMICAL DOSAGE IN RELATION TO SETTLING AND FILTERING OF RAW SEWAGE

BY WILLEM RUDOLFS, J. H. BRENDLEN AND WM. T. CARPENTER

Industrial Engineering Chemistry, News Ed. **13**, 302 (1935)

The experiments described in this article were carried out at the Coney Island, N. Y., experimental sewage treatment plant. The pur-

pose was to obtain chemical cost data for varying degrees of sewage purification. The raw sewage was screened and passed into a mixing chamber having two sections. After being dosed with a suspension of lime in the first section, the sewage passed to the second section where a solution of iron was added. Mixing was obtained by air agitation and paddles. The sewage mixture was then divided into two portions and passed into two circular clarifying tanks, 6 ft. in diameter, where the detention period was about two hours. One of the tanks was equipped with a Laughlin magnetite filter. In order to obtain good clarification, it was necessary to adjust the pH between 9.2 and 9.5 by the addition of 45 to 50 p.p.m. of calcium oxide and to add a minimum of 7.5 p.p.m. of iron. Purification was measured by determining the reduction in B.O.D. and suspended solids.

The purification increases with an increase in dosage of chemicals but not in direct proportion to the cost. The cost becomes greater the higher the degree of purification obtained. Removal of 50 per cent of non-settleable solids with plain settling requires, per million gallons of sewage, about $8.80 worth of chemicals, whereas 80 per cent removal requires an expenditure of $12.80. There was considerable difference in cost of chemicals between plain settling and settling plus filtering. With settling plus filtering, the corresponding chemical cost was about $3.00 and $6.00. Based on B.O.D. reduction, the difference in cost of chemicals for equal purification by settling and settling plus filtering is not as great. Costs were computed on the basis of ferric chloride at $40.00 and calcium oxide (94 per cent) at $12.00 per ton.

P. D. McNamee

TREATING CONEY ISLAND'S SEWAGE

Engineering News-Record, **115**, 489–495 (October 10, 1935)

The new Coney Island plant is the first unit to be operated of New York's program of 38 proposed new treatment plants. It is designed to treat 35 m.g.d. from a population of 300,000 in an area of 1700 acres. Present population is 172,000, and future extensions can increase plant capacity to care for an estimated 1960 population of 1,200,000 in a tributary area of 11,450 acres.

Sewage enters the new plant through an existing 84 in. trunk line, then passes through hand cleaned, coarse screens to the pumps which have a capacity of 58 m.g.d. There are no grit chambers, and screenings are pulped and returned to the wet well. Sixty (60) p.p.m. of hydrated lime and 36 p.p.m. of ferric sulphate are fed into the 48 in. force main by a venturi-actuated dosage mechanism from dry feed

machines. Following 1½ minutes rapid mix provided by seven around-the-end baffles, there are 11.4 minutes of gentle rotary mix provided by flocculating paddles operating from a longitudinal drive shaft. The coagulated sewage is then distributed to four settling tanks from a 10½ ft. diameter by 18 ft. down-flow octagonal distributing well by 30 in. pipes, symmetrically placed to give each tank an equal solids load.

The settling tanks are 90 ft. diameter, of the radial flow mechanically-cleaned type, with a copper alloy, slotted, peripheral weir and skimming blade.

Eight concrete sludge digestion tanks, 54.5 ft. diameter by 28 ft. average depth provide 1.6 cu. ft. per capita storage, and are each equipped with floating gasholders of 25,000 cu. ft. capacity. Vacuum filtration of the sludge will be accomplished by a single filter with 570 sq. ft. area. The sludge will be conditioned with 6 per cent of ferric sulphate or 13 per cent hydrated lime based on the dry solids content. Sludge is to be used for filling nearby land and for top soil dressing by the Park Department. Electric power for plant operation is to be provided by sludge gas engine driven generators. The digestors and buildings are to be heated by hot water from heat exchanges utilizing waste engine exhaust gases.

The plant effluent is to be chlorinated and discharged through a 72 in. concrete pressure conduit 1½ miles long, extending to Rockaway Inlet and terminating in a 20 ft. diameter by 18 ft. concrete chamber from which a grid system of cast iron pipes and discharge T's distribute the effluent into tidal waters. The concrete distribution chamber was precast on shore and floated into place over a previously prepared wood pile foundation. The 72 in. concrete outfall was precast in 24 ft. sections at Kenilworth, New Jersey, then trucked 10 miles and loaded on to lighters. Two 24 ft. sections were joined by means of two 1½ inch tie bolts along the horizontal axis and lowered into position, using a collapsible pilot point to assist in making the submarine connection. Joints on the pipe were sealed with a rubber gasket, giving flexibility to the line.

During the winter the plant will be operated as a plain sedimentation plant, chemical treatment and chlorination being unnecessary.

R. W. KEHR

CHEMICAL-MECHANICAL TREATMENT OF SEWAGE. II. COAGULATION CHEMICALS AND THEIR APPLICATION*

By P. B. Streander and M. J. Blew

Public Works, **66**, 30 (August, 1935)

Ferric chloride is preferable for conditioning sludge below pH 7.0. It must be solution fed through lines of ferric chloride resistant material. Ferric sulphate is more easily handled, has an appreciable heat of solution in the anhydrous state, can be dry fed, but is also quite corrosive. Chlorinated copperas requires, theoretically, 0.11 lbs. of chlorine per pound of ferric sulphate to give 0.19 lbs. of ferric chloride and 0.48 lbs. of ferric sulphate. In practice about 0.15 lbs. of chlorine are usually used. All iron salts are about equally effective on the basis of ferric iron and the cost per unit of ferric iron should govern. Quicklime requires about 5 lbs. of water per pound of lime for slacking, and a temperature of 140–180° F. It requires continuous mixing and there should be storage capacity for the milk of lime of about 6 hours usage to obtain uniform feed.

R. W. Kehr

CHEMICAL-MECHANICAL TREATMENT OF SEWAGE. III. PRE-TREATMENT, FLOCCULATION, PRECIPITATION AND FILTRATION

By P. B. Streander and M. J. Blew

Public Works, **66**, 22 (September, 1935)

Pre-treatment in a sedimentation tank or "coal mat" filter tends to reduce the load and smooth out variations in flow. The use of chemical sludge from the final tanks is beneficial but the use of inert substances is of questionable value except for conditioning of sludge.

Mixing of chemicals with sewage is best accomplished by means of a short rapid initial mix, either mechanically or with compressed air, followed by a long period of gentle agitation to bring the floc into intimate contact with sludge particles.

Continuous removal of settled sludge is necessary. Both radial flow circular tanks and rectangular tanks are good, provided the velocity of

* *Editor's Note.* For abstract of first paper of this series, see This Journal, **7**, 949 (Sept., 1935).

flow does not exceed 2 ft. per minute, or the settling rate 1200 gallons per square foot per day. Two to three hours detention should be provided, or one to two hours where the effluent is filtered. Grease can be largely removed by pre-aeration with baffles and scum removal equipment on the settling tank.

R. W. KEHR

CHEMICAL–MECHANICAL TREATMENT OF SEWAGE. IV. MECHANICAL FILTRATION. SLUDGE TREATMENT

BY P. B. STREANDER AND M. J. BLEW

Public Works, **66**, 15 (October, 1935)

Filtration of the settled sewage should be a part of chemical treatment since it saves chemicals and permits smaller sedimentation tanks to be used. Filters may be either of the upward or downward flow type; using a variety of filtering media such as anthracite and crushed magnetite. Filtering rates have largely been inherited from waterworks practice, being 2 gallons per square foot per minute based on the average flow, but not exceeding 4 gallons per square foot per minute. Such filters should accomplish 90 per cent removal of suspended solids. Wash water should be returned to the raw sewage.

Ferrous salts usually produce a sludge containing from 2 to 4 per cent dry solids, ferric sulphate one containing from 3–5 per cent, while ferric chloride sludge usually ranges from 4–6 per cent. Where sufficient alkalinity is present to require no lime, ferric coagulation will increase the quantity of dry solids about 10 per cent above that calculated from the decrease in suspended solids, but when both lime and ferrous or ferric salts are used, the increase is between 20 and 40 per cent.

R. W. KEHR

EXPERIMENTS IN CHEMICAL SEWAGE TREATMENT AT LIBERTY, N. Y.

BY W. A. HARDENBERGH

Public Works, **66**, 31 (October, 1935)

The plant consisted of duplicate, mechanically-cleaned rectangular sedimentation tanks, sludge digestion tanks, sludge beds and a chlorination tank. The problem was to provide partial treatment during about 100 days of the summer for .75 m.g.d. of sewage with a B.O.D. of 300–

700. Various chemicals were first applied 1½ miles away from the plant in an 18 inch sewer to obtain mixing during passage of sewage to the plant. Results were unsatisfactory and an air agitated mixing tank was built. Good results were obtained with lime, prechlorination and "ferrisul" and with "blackalum" alone, adding the coagulant at about the ⅓ point in the mixing tank with a minimum of air agitation following the addition of chemicals. Activated carbon decreased odors, improved draining qualities, and decreased digestive activity when added to the sludge digestion tanks.

R. W. KEHR

THE SEWAGE TREATMENT WORKS OF YORK, NEBRASKA

BY F. M. VEATCH

Water Works and Sewerage, **82**, 305 (Aug., 1935)

A chemical sewage treatment plant designed to treat an average daily flow of 0.7 m.g.d. was put into operation at York, Nebraska, on October 1, 1934. The sewage is screened and passed through a preliminary settling tank before the coagulant is added. Sludge is digested in a heated digestor and is dried on open beds. The beds are not underdrained and no filtering material is used as they are located on land subject to frequent flooding. The sludge formed by chemical precipitation is returned to the raw sewage sump, where it is mixed with the incoming sewage before it goes to the preliminary settling tank.

The plant is operated by one man, who is on duty from 7:30 A.M. to 5:00 P.M. Chemicals are fed during this period only, flow gaugings having shown that slightly over 70 per cent of the flow occurs between these hours. Chemical treatment has consisted of 120 lbs. of ferric chloride (from scrap iron and chlorine) and 180 lbs. of hydrated lime per million gallons while the attendant is on duty, equivalent to 82 lbs. of ferric chloride and 122 lbs. of lime per million gallons for the entire flow. The ferric chloride costs approximately five cents per pound exclusive of the labor of collecting and crushing the tin cans. The total cost of chemicals is about $5.50 per million gallons. No routine control tests have been made, but numerous catch samples have shown a methylene blue stability of 12 to 14 hours and the removal of suspended solids is practically complete, although the effluent is noticeably turbid when examined in a glass beaker. No trouble has been encountered in the digestion of the chemically precipitated sludge.

R. S. SMITH

SPRAY DRYING OF SLUDGE

By John R. Downes

Water Works and Sewerage, **82**, 323 (Aug., 1935)

A plant size unit for the spray drying of digested sludge was installed at the Joint Sewage Treatment Works of Plainfield, N. J., in 1933 and is drying all of the digested sludge from a population of 50,000, operating 9 hours per day, 6 days per week.

Digested sludge of 5 per cent solids is concentrated to 10 per cent solids by flotation with alum, using 4 lbs. of alum per ton of sludge. This concentrated sludge is atomized by a cage type spraying bowl, 6 inches in diameter, turning at 9600 r.p.m., which delivers the atomized sludge to the top of the drying chamber, a carefully insulated octagonal chamber, 20 ft. in diameter and 20 ft. high. Although the openings in the spraying bowl are about 1 in. deep and 1¼ in. long, there has never been any tendency for them to clog. Heat is supplied by the combustion of soft coal in a brick lined furnace, fed by a thermostatically controlled underfeed stoker. The heated air and combustion gases at 700° F. enter the drying chamber annularly at the top and are withdrawn half a minute later at the bottom at a temperature of 220° F. The temperature of the exit gas is maintained by thermostatic control of the sludge feed, and this temperature determines the moisture content of the product. By a balance of the volume of air supplied, size of inlet ports and fire bed resistance, a slight vacuum is maintained in the drying chamber. The air is circulated in an almost closed system to gain thermal economy.

Sludge of 10–12 per cent solids is dried at the rate of 70 lbs. per minute to a product resembling good loam and containing about 30 per cent of moisture at a cost, under Plainfield conditions, of $9.86 to $12.04 per ton of dry solids. There has been no difficulty in selling the product at $10.00 per ton, equivalent to $12.04 per ton of dry solids. The 30 per cent moisture sludge may be burned by blowing it back over the fire. When handled in this manner, it burns instantly with terrific heat and without odor and will supply about 33 per cent of the heat needed for the drying process.

To date no attempt has been made to dry sludge with a higher solids content than 12 per cent as regular procedure, because with more concentrated sludges the power costs for pumping and atomizing mount rapidly. It has been demonstrated, however, that sludge containing 30 per cent solids can be atomized by the spray unit. Digested sludge does not give off offensive odors in the drying process, but raw sludge cannot be successfully dried without odor under present conditions.

R. S. Smith

THE USE OF ANTHRACITE IN SEWAGE SLUDGE BEDS

By R. R. Cleland and G. S. Scott

Public Works, **66**, 13 (September, 1935)

In a series of tests made on two open and two covered sludge drying beds, one of each covered with 6 inches of sand of .26 mm. effective size and 2.00 uniformity coefficient and the others with 6 inches of anthracite of .37 mm. effective size and 2.89 uniformity coefficient, no significant difference was found in the drying rates using partially digested Imhoff sludge conditioned with alum. The effluent from the sand beds was slightly better due to the smaller effective size of the sand. The cost of the anthracite might be less in some places and if the sludge is to be burned the anthracite picked up from the bed adds to the fuel value of the sludge.

R. W. Kehr

PIONEER ACTIVATED SLUDGE PLANT STILL IN SERVICE

By E. W. Steel

Engineering News-Record, **115**, 222 (August 15, 1935)

Built in 1916, the San Marcos plant treats an average of 0.3 m.g.d. of fresh domestic sewage and a maximum of 0.435 m.g.d. The original plant consisted of a rectangular aeration tank and hopper bottom settling tank with excess sludge disposal by irrigation on nine acres of land. The plant was enlarged in 1925 by changing a 40-ft. circular sump into an aeration tank and constructing another sedimentation tank and still later a bar screen and grit chamber. The effluent is now chlorinated with hypochlorite. The use of open end pipes requires about 3 cu. ft. of air per gallon of sewage with 7–10 hours detention. The operating cost is about $37.00 per m.g. and plans have been made to replace it with an Imhoff tank and sprinkling filter.

R. W. Kehr

ACTIVATED CARBON FOR ACTIVATED SLUDGE PLANTS

Anon

Public Works, **66**, 24 (August, 1935)

Experimental split dosage of 35 lbs. per day of activated carbon to the sewage at Newark, New York (contributing population 9000) had

the following results: Scum formation reduced 75 per cent, gas production increased 25 per cent with increased fuel value, faster drying and odorless sludge, and no effect upon clarification.

R. W. KEHR

SEWAGE TREATMENT FACILITIES IN THE UNITED STATES

ANON

Engineering News-Record, **115**, 224 (August 15, 1935)

A total population of 76,714,000 in 44 states reporting are served by public water systems and of these 80 per cent are also served by sewers. Sewage treatment plants numbering 3697 serve 22,000,000 people. Texas treats 87 per cent of its sewage, Illinois 85 per cent, and Maryland, Rhode Island, Oklahoma, New Mexico, California and Arizona 74 per cent or more, each. Primary treatment only predominates. A tabulation showing the number and type of plants in each state is given.

R. W. KEHR

SEWAGE TREATMENT FOR A SMALL VILLAGE

BY G. L. ROBINSON

Public Works, **66**, 27 (September, 1935)

The Waverly, Pa., plant is designed to handle 40,000 gallons per day of strictly domestic sewage. It consists of a ¾ in. opening bar screen, Imhoff tank with over 2 hours sewage flow detention and 400 cu. ft. sludge capacity, dosing siphon, sprinkling filter with 1½–3 in. stone operating at a rate of 1.8 m.g.d. per acre, resettling tank, chlorinator and sludge drying bed with 1½ square feet per capita. Laboratory equipment is provided to make settleable solids, relative stability and residual chlorine tests. The estimated cost of the plant is $65,200.00. It is a work relief project.

R. W. KEHR

TANNERY WASTE TREATMENT AT ROCKFORD, MICHIGAN

By G. E. Hubbell

Water Works and Sewerage, **82**, 331 (Aug., 1935)

Rockford, Michigan started operation of a sewage treatment plant in October, 1934, involving plain sedimentation and mechanical dewatering of sludge. The principal industry of the town is tanning and shoe making and the sewage is predominantly tannery waste.

The flow varies widely, averaging 1,500,000 g.p.d. when the tannery is in operation and 130,000 g.p.d. when the tannery is shut down. The sewage contains spent chemical waste, hide, hair and fleshings. It has a 5-day B.O.D. of over 600 p.p.m. and a pH of 9.0. The maximum hourly suspended solids content is 1200 p.p.m.

The sewage is settled in two rectangular tanks with submerged orifice-type inlets and mechanical scrapers. The sludge is conditioned with lime, using 6.4 per cent on a dry solids basis, and dewatered on a vacuum filter with 100 sq. ft. filtering area. The sludge feed to the filter averages 94 per cent of moisture and the filter cake 70 per cent of moisture with an average filter rate of 2.84 pounds of dry solids per sq. ft. per hour. Conditioning with ferric chloride and lime would increase the filter yield, but the cost of ferric chloride would be greater than the cost of operating the filter for the additional time necessary with lime conditioning alone. The sludge is being filtered at a cost of $0.28 per lb. of dry solids, exclusive of fixed costs. The filter cake produced, containing lime and organic material, is a good soil builder and is readily disposed of on adjacent farm land.

R. S. Smith

HAZARD OF INFLAMMABLE WASTES DISCHARGED INTO SEWER SYSTEMS

Anon

Water Works and Sewerage, **82**, 323 (Aug., 1935)

A fire which occurred in the sewage treatment plant of Middletown, New York, is believed to have been caused by the ignition of gasoline wastes. The flames followed the sewage into the building appearing first in the grit chamber and then at the screen chamber. The fire was extinguished in about an hour with Foamite by the city fire department.

Fortunately there was no serious damage to the plant equipment, but the experience emphasizes the importance of preventing the discharge of inflammable wastes into sewer systems.

R. S. SMITH

SEWER CLEANING WITH RUBBER BEACH BALLS

BY A. M. RAWN

Water Works and Sewerage, **82**, 359 (October, 1935)

Los Angeles County Sanitation Districts have developed a method of cleaning sewers, using the type of inflated rubber beach ball commonly seen at playgrounds and beach resorts. These balls are manufactured in sizes from 6 to 30 inch diameter. As used for cleaning sewers the ball is inflated and then covered with canvas or burlap with sewed seams. A trail line somewhat longer than the distance between manholes is attached to this cover and the ball inserted in the sewer. Sewage backs up in the manhole until the pressure is great enough to force water under the ball, when it commences to move downstream. The ball affords enough obstruction to maintain a continuous high-velocity jet under it, sluicing all movable material ahead to the next manhole. Brick, stones, bottles and loose metal are all easily moved ahead. About the only fixed obstruction which will stop the ball is a root mass or some similar material tightly wedged in the pipe. If it should strike a joint fin or similar immovable obstruction, the ball is indented to the necessary degree and continues forward.

On one occasion a 24-inch siphon, 800 feet long, was cleaned. It took the ball thirty-six hours to pass through the siphon, but it removed a truckload of sand, gravel, bricks and boulders as well as a half dozen flash boards. The ball was put through the siphon again immediately and appeared at the outlet in less than an hour. In ordinarily dirty sewer lines, three men are employed and have cleaned in excess of four miles of sewer in an eight hour working day. The maintenance crew carry inner tube vulcanizing patches, and small holes in the balls are readily repaired.

R. S. SMITH

LAYING A THOUSAND-FOOT SEWAGE SEA OUTFALL

ANON

Public Works, **66** (September, 1935)

At Asbury Park, N. J., a 1000-foot wrought iron pipe outfall was laid into the ocean on a sand bottom. The pipe was 24 in. in diameter with ½ in. thick walls, shop welded into 60 ft. lengths from 20 ft. mill lengths. Each weld was protected by a 2 ft. 6 in. by ½ in. wrought iron collar. The pipe was welded on shore into 180-ft. lengths and floated, with some ballast water for stabilization, as each 180-ft. section was welded on and skidded into the water by means of a donkey engine pulling a cable through an anchored sheave.

R. W. KEHR

PRE-TREATMENT OF SEWAGE FOR GREASE REMOVAL

BY HARRISON P. EDDY, JR.

Civil Engineering, **5**, 138 (March, 1935)

Oil and grease at the sewage treatment plant sometimes creates difficulties because of the clogging of fine screens; interference with aeration processes; forming of unsightly scums; influence upon Imhoff tank digestion; or the occurrence of sleek at the point of discharge. The quantity of oil and grease varies widely, but may be visualized as ether soluble matter equivalent to solids of 53 parts per million, or about 0.05 pound per capita daily. It is regarded as including some 28 per cent of the suspended solids in sewage. Efforts to capture such oil and grease do not show high removals.

Removal of oil and grease may be effected in special tank devices or else may be a feature of the operation of settling tanks. Removal is generally by skimming. The use of acid for cracking is limited and chiefly to industrial wastes.

Special or applied devices for the removal of oil and grease include: (*a*) Scum boards in the tanks and hand skimming; (*b*) siphon chambers, as at Washington, D. C.; (*c*) skimming-detritor tanks, as at Akron, Dayton and Allentown, where grease is skimmed by a floating boom and removed to drainage beds; (*d*) by aeration, patterned upon Imhoff and as installed at Springfield and Pasadena; (*e*) sludge scraper mechanism, arranged to provide skimming and concentration of the scum, and either with or without pre-aeration in approach channels; (*f*) water jets, as at

Fitchburg and North Toronto; and (*g*) grease traps which, in World War cantonment practice, were constructed with capacities of about $\frac{2}{3}$ gallon per capita and were characterized by steep sides, conical bottom and the smaller diameter of the eduction pipe which removes the solids.

Oil and grease recovered by treatment devices is buried, burned or digested with the sludge. In the case of burning preliminary drainage is found advantageous.

FRANK C. TOLLES

SEWAGE DISPOSAL IN THE CITY OF NEW YORK

BY RICHARD H. GOULD

Civil Engineering, 5, 158 (March, 1935)

The article cited is itself an abstract of a paper which was delivered before the Sanitary Engineering Division, American Society of Civil Engineers, January 17, 1935.

Sewage treatment in New York City dates back to 1884, most of the processes being proprietary and since abandoned. Existing works are as follows:

8—Fine Screen Plants	treating 93 m.g.d.
6—Sedimentation Plants	treating 18 m.g.d.
2—Coarse Screening Plants	treating 25 m.g.d.
16—Plants	serving 1,250,000 people and treating 136 m.g.d.

Pollution effects from the city and other adjacent areas are evident in the harbor and tributary waters. In slack water such effects are made manifest by decomposition and the accompanying ebullition of gas. Bathing in the inner harbor has been prohibited and it is affected at other points.

Tidal movements are slow to renew harbor waters and, in some locations, sewage is retained for twenty days before being passed to sea.

The degree of sewage treatment that is needed depends, among other things, upon the use of the waters into which the effluent is discharged. The removal of sludge appears to be more important than is indicated by the 5-day B.O.D. test which is regarded locally as to be used with caution. Available processes include short period sedimentation, chemical precipitation, and activated sludge treatment. Space is often critical, but where a site is available and high degree treatment is necessary, the power cost for aeration in the activated sludge process with 0.7 cent power and 100 per cent load factor is regarded as costing "from 35

to 40 per cent of the cost of chemicals'' necessary for chemical treatment of lower degree of effectiveness. Likewise, it is thought that power costs are more stable than the price of chemicals and that the activated process is still short of its ultimate development, particularly for reduced treatment. However, chemical processes are regarded as having a field in New York.

The barging of sludge to sea appears to offer no objections, and this method coupled with the recovery of fertilizer for municipal use seems to be the method locally most suitable.

Informal plans for treating New York sewage call for 38 plants to treat an ultimate flow of 1,764 m.g.d. Largest among these is the Wards Island activated sludge plant (426 m.g.d. ultimate) work on which has been suspended pending additional financing. Federal aid has been extended to the Coney Island Plant (35 m.g.d. present, 140 m.g.d. future) which will provide chemical treatment and chlorination during the summer and sedimentation during the winter. Sludge will be digested and filtered. The selection of the type of plant was based upon deficiency in area, upon the high cost of power, and upon the restricted need for great reduction in B.O.D.

New York's need for sewage treatment is increasing and it may be expected that appreciation of this will result in substantial construction program.

FRANK C. TOLLES

STUDIES OF SEWAGE PURIFICATION. II. A ZOOGLEA-FORMING BACTERIUM ISOLATED FROM ACTIVATED SLUDGE

BY C. T. BUTTERFIELD

Public Health Reports, **50**, No. 20 (May 17, 1935), pp. 671-684, also *Public Works*, **66**, No. 5 (May, 1935), pp. 15, 16, 18 and *Public Works*, **66**, No. 6 (June, 1935), pp. 23-26

The predominance of zoogleal masses in activated sludge, especially when the process is working most efficiently, prompted their isolation and study in pure culture. Although zooglea have been previously noted in connection with sewage purification, their isolation and study under pure culture conditions have not been reported. Since the organism does not grow readily on agar or gelatin, the method employed was to wash a clump of organisms repeatedly with distilled water to which nutrient broth had been added to prevent the dispersion from the gelatinous matrix, then washing in dilution water until dispersion

occurs and planting in serial dilutions. Pure cultures were usually obtained above the 1/100 dilution.

The zooglea-forming bacterium isolated is an aerobic, non-spore forming, motile, rod-shaped organism, averaging 1.5 by 3 microns. It forms a floc in liquid media and grows best between 28° and 30° C. and at a pH of from 7–7.4. It raises the pH of nutrient broth containing peptone, but fails to produce gas with the common sugars in broth.

Studies were made of its ability to produce sludge in both synthetic media of the approximate strength of sewage and in sterilized sewage. To obtain a large size floc with synthetic sewage, .2 gm. per liter of short cotton fibers was added. This sludge when built up to 2000 p.p.m. suspended matter had a sludge index of 15 to 20 and removed an average of 72 per cent of the B.O.D. from a sludge-synthetic sewage mixture during 3 hours aeration as against a maximum of 5 per cent in a control test using non-sludge forming bacteria. Similarly, with autoclaved sewage adjusted to pH 7.0, a good sludge was produced without the addition of cotton fibers which removed an average of 68 per cent of the B.O.D. after 3 hours aeration. The addition of *Colpidium* to the pure culture of zooglea clarified the supernatant after settling, but increased B.O.D. removals only slightly. It is suggested that an adequate knowledge of this and related organisms may be of considerable significance in sewage purification processes depending upon biological activity.

R. W. KEHR

BOOK REVIEW

The Work of the Sanitary Engineer. By Arthur G. Martin. Published by McDonald & Evans, London, England, 1935. Cloth, 6 x 9 in. 472 pp.; including 26 pp. Index. Illustrated. British price, 16 s.

The author, Mr. Arthur G. Martin, M.Inst. C.E., is well qualified to write a book on the work of the Sanitary Engineer, through his long experience in matters relating to municipal sanitation and his contact with the younger engineers. His book is offered as a handbook for engineering students and others concerned with public health. Actually, it is a text-book for British students desiring a general knowledge of sanitary administration (pp. 3–51), water supply (pp. 55–185), drainage and sewerage (pp. 189–249), sewage disposal (pp. 253–384), disposal of refuse (pp. 387–419), flood prevention (pp. 423–432), land drainage (pp. 433–439) and coast protection (pp. 440–446). In covering, within a compass of 446 pages of text, such a wide range of subjects, it is

difficult to give much detail. As an interesting exposition of the various phases of sanitary engineering from a British standpoint, the book is well worth reading, particularly for those who are desirous of making a comparison of British and American practice.

The chapters on sanitary administration and methods of handling municipal work summarize the practice in Great Britain, and its legal aspects. The review of British practice in sewage disposal is timely, but fails to give a proper perspective of the present use in Great Britain of the various procedures described. In a chapter on activated sludge, the author presents a miniature of his excellent book, "The Activated Sludge Process." However, his opinions on detail lack the breadth which a working knowledge of American practice should have given and contain many minor errors as to detail. In his prediction on the future of the activated sludge process, he may be speaking for British practice when he says it is probable the activated sludge process will never supersede methods already in use and is far more likely to be used in conjunction with sedimentation tanks and filters than to supersede them. Such an opinion runs counter to American practice, wherein a recent survey indicates that at the present time in the United States, the activated sludge process is used in treating the sewage of more population than any other process. A very important factor in the growth in the United States has been developments made by American engineers from tests and operating experience on a large scale in a variety of situations.

To discuss the various details which interested the critic would take more space than this review warrants. Suffice it to say that Mr. Martin has written a readable book which will interest the American engineer. On the other hand, having stepped out of British experience to draw on American practice, the author should have studied the field more carefully, with a view to indicating where American practice might well be studied by British engineers in solving their sanitary problems of water supply and sewerage. As a book for students, more references should be given, preferably following each chapter, so that a student might follow up the various topics of the text in standard treatises.

Possibly the shortcomings of the book will be overcome in future editions. It is the type of book which might well be made available in rewritten form for general students in science, medicine or public health in the United States.

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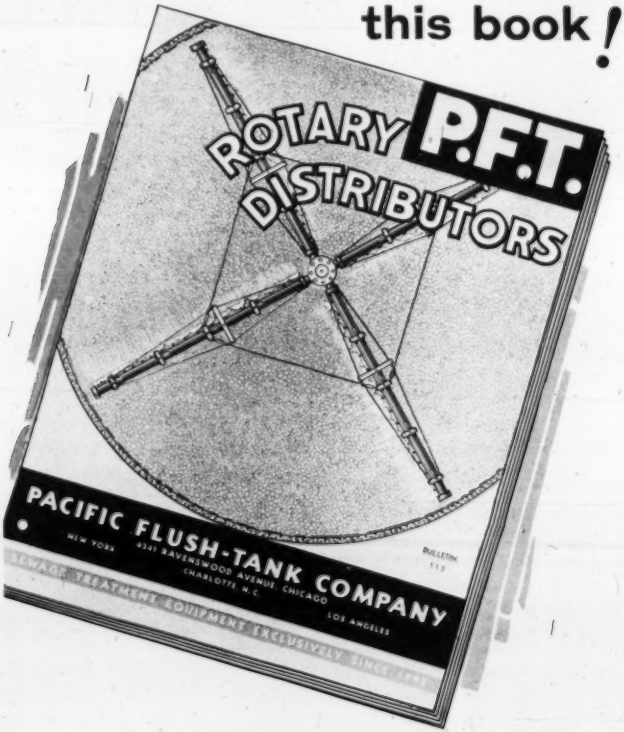

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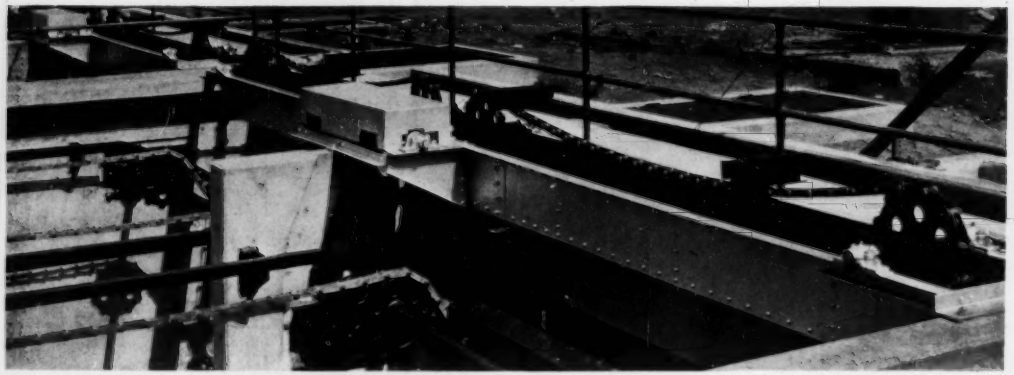

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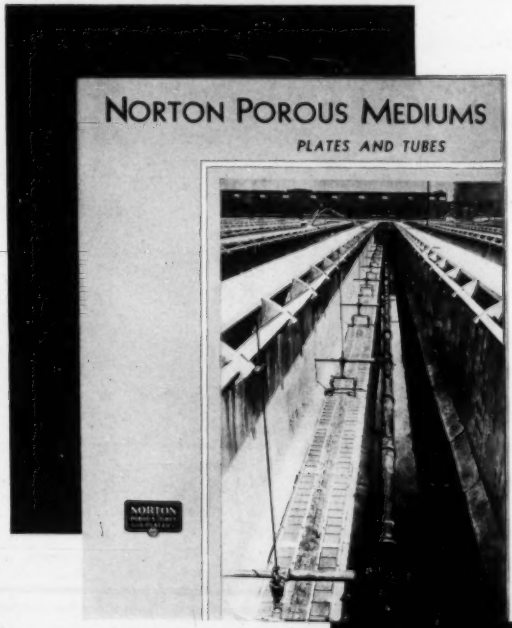

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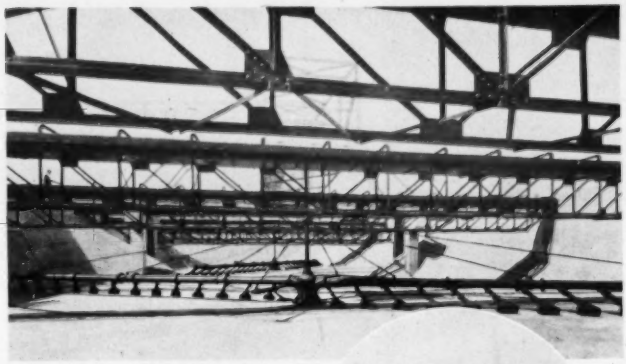

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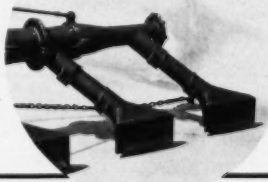

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